IMPLEMENTATION OF INNOVATION AND ETHICS USING VIDEO-BASED LEARNING IN NERVE SURGERY

Andrew Yee

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IMPLEMENTATION OF INNOVATION AND ETHICS USING VIDEO-BASED LEARNING IN NERVE SURGERY

IMPLEMENTATIE VAN INNOVATIE EN ETHIEK MET BEHULP VAN VIDEO-GEBASEERD LEREN BIJ ZENUWCHIRURGIE

(met een samenvatting in het Nederlands)

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TABLE OF CONTENTS

	List of Figures	xi
	List of Tables	xii
	List of Abbreviations	xiii
	Abstract	xv
CHAPTER 1	Introduction and Background	1
	Surgical Innovation	3
	Ethics in Surgical Innovation and Anatomy	4
	Diffusion, Dissemination, and Implementation	7
	Expert Performance	13
	Example-Based Learning and Cognitive Load Theory	17
	Video-Based Learning in Surgery	20
	Outline of Thesis	23
	References	25
PART I: ESTABLISHING VIDEO-BASED LEARNING IN NERVE SURGERY		
CHAPTER 2	Video-Based Learning in Surgery: Establishing Surgeon Engagement and Utilization of Variable-Duration Videos	37
	Abstract	38
	Introduction	39
	Methods	40
	Results	44
	Discussion	51
	Conclusion	54
	References	56
CHAPTER 3	The Role of Surgical Video on Resident Performance of Carpal Tunnel Release: A Cadaveric Simulation-Based, Prospective, Randomized, Blinded Study	59
	Abstract	60
	Introduction	61
	Methods	62
	Results	65
	Discussion	69
	Conclusion	71
	References	72

CHAPTER 4	Knowledge Acquisition of Electrodiagnostic Indications for Cubital Tunnel Surgery Using Video-Based Learning	77
	Abstract	78
	Introduction	79
	Methods	80
	Results	84
	Discussion	87
	Conclusion	91
	References	92

PART II: ADDRESSING ANATOMICAL ETHICS IN SURGICAL INNOVATION

CHAPTER 5	The Role of Eduard Pernkopf's Atlas of Human Anatomy in Surgical Practice: Nerve Surgeons and Oral & Maxillofacial Surgeons' Assessment	99
	Abstract	100
	Introduction	101
	Methods	102
	Results	104
	Discussion	112
	Ethical Justification	115
	Conclusion	117
	References	118
CHAPTER 6	Ethical Considerations in the Use of Pernkopf's Atlas of Anatomy: A Surgical Case Study	121
	Abstract	122
	Introduction	123
	A Case Study in the Operating Room	124
	History of Pernkopf's Atlas	124
	The Ethical Dilemma	126
	Jewish Ethics and Law	127
	Discussion	129
	Ethics Bottom Line: Return to the Operating Room	135
	Outcome of Surgery	135
	References	136
CHAPTER 7	Summary, Discussion, and Future Perspectives	139
	Summary and Conclusion	140
	Discussion	144
	Establishing Surgeon Engagement in Video-Based Learning	144

Surgical Video Improves Performance by Reducing Operative Errors	146
Compelling Education Videos Teach Clinical Reasoning	147
Advancing Anatomy Ethics in Surgery	150
The Role of Dissemination and Implementation of Innovation	156
Ensuring the Sustainability of Video-Based Learning	158
Future Perspectives	163
References	167

APPENDIX

Dutch Summary Nederlandse Samenvatting	175
Publication List	181
Acknowledgements Dankwoord	189
Biography	193

LIST OF FIGURES

Figure 1.1 Diffusion of innovation.	8
Figure 1.2 Scott's parabola.	9
Figure 1.3 Implementation and deimplementation.	11
Figure 1.4 Dissemination and implementation (D&I) of surgical innovation.	12
Figure 1.5 Knowledge gap in surgical education.	15
Figure 2.1 Longitudinal development of the video-based learning program.	40
Figure 2.2 Comparison of relative audience retention between short and long video forms.	42
Figure 2.3 Visual identification of viral videos by views.	43
Figure 2.4 Comparison of daily sessions/views of Nerve Surgery, YouTube, and PASSIO.	47
Figure 2.5 Audience engagement of educational videos.	48
Figure 2.6 Preferred video duration in multiple practice situations.	50
Figure 2.7 Factors influencing optimal video duration.	52
Figure 2.8 Geographic distribution of views on YouTube.	55
Figure 3.1 Experimental study design.	62
Figure 3.2 Prior carpal tunnel release experience.	65
Figure 4.1 Study design of educational video module.	80
Figure 4.2 "Whiteboard" of full-length video lecture describing clinical judgment.	83
Figure 4.3 Time spent watching the video lectures.	86
Figure 4.4 Relative audience retention of abridged and full-length video lectures.	89
Figure 5.1 The effects of a 4-point ethical proposal on the use of Pernkopf's atlas in surgery.	109
Figure 6.1 Signatures of Pernkopf's illustrators demonstrating Nazi sympathies.	125
Figure 6.2 Relevant anatomical and illustrative plate comparison.	133
Figure 6.3 Saphenous nerve release for managing neuropathic pain.	134
Figure 7.1 Thumbnails for short- and long-format surgical videos.	145
Figure 7.2 Visual depiction and flow of a video-based learning module for clinical reasoning.	149
Figure 7.3 Brachial plexus dissection of a body donor.	151
Figure 7.4 Patient consultation and consent of Pernkopf's atlas in the clinic.	154
Figure 7.5 Whiteboard explanation of triple bypass surgery.	154
Figure 7.6 PASSIO surgical procedures section.	160
Figure 7.7 Interactive chaptering system.	161
Figure 7.8 New model for continuing professional development (CPD).	164
Figure 7.9 Surgical feedback and coaching using photos.	165

LIST OF TABLES

Table 2.1 Comments of support, dissemination, and implementation.	45
Table 2.2 Geographic distribution of video views for YouTube and PASSIO.	49
Table 2.3 Total number of videos and video performance by surgical specialty.	53
Table 3.1 Open-response feedback on learning materials.	64
Table 3.2 Demographics, confidence, and baseline technical skills of participants.	66
Table 3.3 Reliability and validity of performance measure.	67
Table 3.4 OSATS performance of participants.	68
Table 3.5 Number of participants performing at least one operative error for each category.	69
Table 3.6 Usage of provided learning materials during study period.	69
Table 4.1 Evidence-based principles guided by the cognitive theory of multimedia learning.	82
Table 4.2 Pre- and post-lecture and retention assessment scores.	85
Table 5.1 Demographics of survey respondents.	105
Table 5.2 Survey responses to use or not to use Pernkopf's atlas in nerve surgery.	106
Table 5.3 Survey responses to use or not to use Pernkopf's atlas in oral & maxillofacial surgery.	107
Table 5.4 Types of anatomical resources used in nerve surgery and oral & maxillofacial surgery.	111
Table 5.5 Types of anatomical atlases used in nerve surgery and oral & maxillofacial surgery.	112
Table 5.6 Comparison of anatomical plates: Pernkopf vs. Netter.	113

LIST OF ABBREVIATIONS

AAOMS – American Association of Oral and Maxillofacial Surgeons
ABS – American Board of Surgery
ACCP – American College of Chest Physicians
ACGME – Accreditation Council for Graduate Medical Education
ACOMS – American College of Oral and Maxillofacial Surgeons
ASTMJS – American Society of Temporomandibular Joint Surgeons
AI – artificial intelligence
AMA – American Medical Association
API – application programming interface
ASPN – American Society for Peripheral Nerve
ASSH – American Society for Surgery of the Hand
B2B – business to business
B2C – business to customer
CLT – cognitive load theory
CMAP – compound muscle action potential
CME – continuing medical education
CPD – continuing professional development
CPT – current procedure code
CTML – cognitive theory of multimedia learning
CV – conduction velocity
D&I – dissemination and implementation
DOI – digital object identifier
EP – expert performance
ETE – end-to-end
IDEAL – idea, development, exploration, assessment, long-term study
IOM – Institute of Medicine
JoMI – Journal of Medical Insight
JoVE – Journal of Visualized Experiments
JTA – knowledge-to-action
LAP-VEGaS – laparoscopic surgery video educational guidelines
MOC – maintenance of certification
NAM – National Academy of Medicine
NSDAP – National Socialist German Worker's Party
OMS – oral and maxillofacial surgery
OSATS – objective structured assessment of technical skills
PARIHS – promoting action on research implementation in health services
PASSIO – PASSIO (Latin for suffering and enduring) Education
PGY – post-graduate year
PRA – physician's recognition award
PRS – plastic and reconstructive surgery
RE-AIM – reach, effectiveness, adoption, implementations, and maintenance
RETS – reverse end-to-side
SAS – statistical analysis software
SETS – supercharge end-to-side
SNAP – sensory nerve action potentials

STEM – science, technology, engineering, and mathematics
VBL – video-based learning

ABSTRACT

An online video-based learning program in nerve surgery was developed in this thesis as an educational framework to (1) translate expertise globally into clinical practice, (2) implement the constant improvements and innovation in surgery which essentially comes to a halt after surgical training, and (3) address the training disparities and need for improved outcomes. Innovation is a vital process for the advancement of surgery and contributes to improved life expectancy and enhanced quality of life. However, this passive process from ideation to implementation can take many decades, an estimated 17 years for just 14% of medical research to translate from benchtop to bedside and influence patient care. The expert-performance approach proposes to identify superior performance, study performance, and create training methods to facilitate cognitive representations associated with expertise. Video is a rich medium to capture expertise and promote visual learning from modeled examples especially in nerve surgery, a specialty with an illustrious history of innovation and defined management paradigms. When combined with expert-performance, video-based learning provides an opportunity to accelerate surgical innovation through the active process of dissemination and implementation. In this thesis, an online video-based learning program in nerve surgery was developed as an educational framework to translate expertise globally into clinical practice by using YouTube for audience outreach and a surgeon-focused platform to maximize educational value. The program recruited 1,500+ surgeons (54% in-practice, 46% trainees) and received 4M+ views (69% outside the U.S.) from across the world. Of the registered users, 43% were active learners at least once a month. To validate this model, learning analytics were introduced to establish surgeon engagement as a benchmark for quality in surgical videos and dynamic lectures teaching clinical reasoning. To examine the role of surgical videos in learning technical skills, novice residents improved performance by having fewer operative errors and improved confidence when learning from videos in a simulated cadaveric study. To teach clinical reasoning to our membership and accompany the surgical videos, a video-based module was designed using the cognitive theory of multimedia learning (CTML) and demonstrated knowledge acquisition and retention in surgeons, indicating potential long-term practice change and adoption of novel evidence-based procedures. Ethical development of innovative procedures is paramount and mandates robust evaluation for safety, efficacy, and effectiveness. In designing training methods to translate expertise and reduce learning curves, an ethical dilemma was encountered regarding the use of an atlas, derived from victims of the Holocaust, in surgery and education. To address this issue, the use of Pernkopf's atlas was assessed in surgical practice to develop a four-point proposal for its ethical handling to include disclosure, bioethical and religious considerations, and remembrance. Based on the authority of the Vienna Protocol, ethical and religious guidelines were created using a four-option framework to permit its use in surgery and education when physicians acknowledge and disclose its immoral origins, in a manner that honors the victims. These combined results indicate video-based learning as an effective approach for the dissemination and implementation of surgical innovation when guided by expert-performance and CTML, and thereby creates a learning

environment to develop guidelines that address ethical issues encountered at the intersection of surgery, anatomy, and education. This educational framework warrants identifying expertise in surgery to expand training opportunities that transcend geographic, economic, racial, gender, and language barriers and address disparities in healthcare across the world.

CHAPTER 1

INTRODUCTION AND BACKGROUND

Based on:

Dengler J, Padovano WM, Davidge KM, McKay VR, Yee A, Mackinnon SE.
Dissemination and Implementation Science in Plastic and Reconstructive Surgery:
Perfecting, Protecting, and Promoting the Innovation that Defines our Specialty.
Plast Reconstr Surg. 2020.

INTRODUCTION AND BACKGROUND

SURGICAL INNOVATION

1

Innovation is a vital process in the advancement of surgery, contributing significantly to improved life expectancy and enhanced quality of life. While there is no uniform view on innovation, it can be defined as either development of a new procedure, substantial modification to an existing procedure, or application of an existing procedure to a new anatomic site or new patient population.^{1,2} Some innovations can be dramatic, which include, but is not limited to organ transplantation, endovascular procedures, and robotic surgery.³⁻⁶ In plastic and reconstructive surgery, diverse innovations like microsurgery,⁷ liposuction,⁸ tissue engineering,⁹ reconstructive prostheses,¹⁰ and composite vascularized allotransplantation¹¹ were driven by the specialty's emphasis on problem solving in heterogeneous patient populations using creativity, entrepreneurship, and a degree of surgeon autonomy.¹²⁻¹⁵ While research is considered a pre-requisite for driving innovation,¹ the process from ideation to implementation can take many decades. It is estimated that it takes 17 years for just 14% of medical research to translate from benchtop to bedside and influence patient care.¹⁶

Innovations in nerve surgery, a subspecialty that is shared between plastic and reconstructive surgery, orthopedic surgery, otolaryngology, and neurosurgery, can be seen in shifts of management paradigms from nerve repair, to grafting, and to transfer.¹⁷ Thomas Kuhn defines a paradigm shift as a fundamental change in the practice of a scientific discipline, or scientific revolution.¹⁸ He describes that a "failure of existing rules is the prelude to a scientific search for new ones and when enough information has accrued against a current paradigm, the scientific discipline is thrown into a state of crisis, and a new paradigm forms with new followers; frequently with an intellectual battle between the new paradigm supporters and old paradigm hold-outs." Poor clinical outcomes following nerve repair were the stimulus for alternative reconstructive strategies. A controversial symposium at Duke University in 1978 illustrated a paradigm shift from nerve repair to grafting during presentations by Leonard Goldner on managing a long radial nerve gap with bone excisions and nerve repair vs. a patient series by Raymond Curtis managing these same injuries with long nerve grafts with improved results.¹⁷

As nerve grafting became a standard of practice, its adopters recognized the failures of increased graft lengths from exceeding critical intervals and deteriorating clinical results.^{19,20} In the early 1990s, nerve transfers began receiving traction as an alternative strategy to reinnervate a target end organ with a nearby donor nerve,²¹ despite being first described in 1911 adaption of a nerve anastomosis.²² Since then, many nerve transfers have been developed to restore motor and sensory function in the upper and lower extremities,²³ and adapted in other patient populations to restore bladder function in lower urinary tract dysfunction,²⁴ upper limb function in cervical spinal cord injuries, stroke, and cervical radiculopathy,²⁵⁻²⁹ and to treat neuroma pain and control prosthetic arms using targeted muscle reinnervation in amputees.^{30,31} The invention

of the operating microscope ushered in the subspecialty of microsurgery, which allowed for the internal neurolysis of peripheral nerves and thereby revealed new anatomical interfascicular neural patterns and motor/sensory topography and specificity.³² Coupled with the discoveries from translational research based on nerve allotransplantation,³³ nerve transfers became another strategy in the reconstructive toolbox for surgeons through the natural diffusion of information facilitated by evidenced-based medicine and traditional peer-reviewed publishing channels.

Natural diffusion of basic science and clinical research occurs through evidenced-based principles that optimize decision-making and emphasizes ethical research.^{34,35} Since 2009, the IDEAL (idea, development, exploration, assessment, long-term study) framework has been used internationally to provide a staged pathway by which surgical procedures should be developed and assessed.³⁶ This includes pre-clinical studies described as the pre-IDEAL stage, followed by concept proof studies in Stage 1, case series and prospective cohort studies in Stage 2A to provide technical description, prospective multicenter exploration cohort studies in Stage 2B to achieve consensus between surgeons, randomized-controlled studies in Stage 3 to compare procedure efficacy, and registries in Stage 4 to provide surveillance on rare events. The process of exaptation, an evolutionary mechanism resulting from a functional shift of an existing trait, used to stimulate innovation in a social system,³⁷ requires safe and efficacious adoption across this system (i.e. nerve transfers being applied in a vulnerable spinal cord injury patient population). International symposia and peer-reviewed academic journals are the traditional channels to share innovations, however surgery is a visual discipline where a written description of a procedure could be more effectively portrayed through a medium like a video.³⁸ In this thesis, video was explored as an effective medium to facilitate surgical innovation and address potential ethical issues that may arise.

ETHICS IN SURGICAL INNOVATION AND ANATOMY

Ethical development and adoption of innovative procedures are paramount to any surgical discipline, and mandate robust evaluation for safety, efficacy, and effectiveness.³⁹ Four major themes become apparent when discussing ethics in surgical innovation: oversight, informed consent, learning curve, and vulnerable patient groups.⁴⁰ Although, there is no uniform view for innovation, most surgeons agree that some form of oversight is essential and its requirements correspond to the degree of innovations – minor modification, major modification, or radically new innovations, and innovations that are new to the institution but validated elsewhere.^{41,42} This can range from formation of specific innovation committees (institutional, regional, and national) to establishing national registries similar to Stage 3 assessment of innovations in the IDEAL framework.³⁶ Acquiring informed consent for innovative procedures is a necessary step that requires more critical observation to disclose information on its innovative nature, evidence or lack thereof, risk and benefits, and potential alternatives to the procedure.^{40,43} Physicians, researchers, and patient advocates facilitate the effective communication of these considerations to patients, considerations that can be enhanced through multimedia presentations.^{44,45}

Major proponents of ethics in surgical innovation are surgeon educators, whose guidance is aimed at reducing the learning curve relating to safe diffusion and adoption of new techniques.⁴⁶ The IDEAL framework includes a description of the learning curve for new technologies, where during the development and exploration phase, innovators are progressing quickly to refine the technical details of an operation, leading towards superior performance, and become comfortable enough to start broadening its indications and applications to an increasing number of patients.⁴⁷ However, complications relating to the learning curve can arise, as seen with the prevalence of bile duct injuries during the introduction of laparoscopic cholecystectomy.⁴⁸⁻⁵⁰ The reduced hospital stay and improved post-operative recovery period offered in laparoscopic cholecystectomy vs. an open approach warranted several decades of research investigating its efficacy,⁵¹ cost-effectiveness,⁵² and methods for reducing bile duct injuries, research that included the development of a safe cholecystectomy training program designed to institute technical criteria for achieving the “critical view of safety” for identification of the cystic duct and artery.⁵³ Most surgeons agree that training is necessary for using new technologies and performing novel procedures, which include hands-on training with animal models or human cadavers, visiting proficient surgeons, presence of a mentor or committee, and models for accreditation.⁴⁰ Ethicists in surgical innovation propose introducing components of a “learning healthcare system” to guide research and debate.⁴⁰ Suggestions to improve quality of care include embedding research through the integration of research and practice and a moral emphasis on learning activities.

Surgeons practice a form of applied ethics by guiding patients and families through complicated and shared decisions to informed consent, living a code of truth and trust, delivering bad news, and dealing with end-of-life issues and plans for palliative hospice care.^{54,55} In the past, ethics training for surgeons was largely an informal process of following examples and mentorship of senior surgeons.⁵⁶ Coupled with the growing complexity of medical and surgical interventions and reduced opportunities for role models and mentors, a formal ethics curriculum was needed to promote continued ethics education for surgeons at all stages of their careers. Through a joint sponsorship in 2008, the *American College of Surgeons* and the journal *Surgery* implemented quarterly case studies examining bioethical dilemmas using a four-option framework, which concludes with an “ethics bottom line” to provide practical methods for surgeon and an approach using a consideration and weighing of diverse solutions to confront ethical issues.⁵⁷ Covered topics varied and included contemporary ethical questions regarding organ procurement from executed prisoners,⁵⁸ therapeutic misconceptions,⁵⁹ conflicts of interest concerning implants,⁶⁰ sharing clinical photographs in the digital age,⁶¹ and conflict of values judging medical negligence.⁶² Conflict of interest can potentially comprise clinical judgment and thereby prevent the acceptance of innovation.^{63,64}

Ethical issues can arise in the anatomical sciences regarding surgery and innovation. The specialty of plastic and reconstructive surgery is considered by some a specialty of anatomy and innovation,⁶⁵ requiring creative strategies based on scientific evidence to manipulate anatomy and reconstruct uncommon or difficult defects. For example, opponensplasty is traditionally indicated for restoring thenar function in

median nerve defects. However, in a rare case where resection of a synovial sarcoma would create a median nerve defect in the forearm, requiring post-operative irradiation, thus making a splint for protection of a tendon transfer a contra-indication, a surgeon could consider transferring the abductor digiti minimi nerve branch to the thenar nerve branch,⁶⁶ by using a motor nerve graft sourced from the nearby anterior interosseous nerve.^{67,68} To successfully perform such an intricate procedure requires knowledge of neural branch pattern and interfascicular anatomy, a knowledge derived from hands-on experience, anatomical textbooks, or peer-reviewed scientific articles. Surgical anatomy is the basis for all surgical specialties, and its users need to consider the ethical origins from which the data and human tissues were sourced.⁶⁹

The *Topographische Anatomie des Menschen* (Topographical Anatomy of Man) by Eduard Pernkopf is a highly regarded atlas featuring detailed illustrations of meticulous anatomic dissections.⁷⁰ However, its use is surrounded by controversy due to Pernkopf and his medical illustrators' (Lepier, Endtresser, and Batke) affiliation to the Nazi Party (NSDAP).⁷¹⁻⁷⁴ Accounts of the history in the advancement of the anatomical sciences during the early 1900s document ethical transgressions during the "Third Reich."⁷⁵ Unlike the present practice of body procurement using willed donor programs, German anatomists during this period produced knowledge and procured bodies from victims of the Nazi regime, including executed prisoners.⁷⁶⁻⁷⁸ Inquires into the origins of Pernkopf's atlas began in the 1980s when Weismann and Williams revealed that Pernkopf and his illustrators' were NSDAP members.^{71,74} Williams addressed the atlas as a "troubled masterpiece." A public debate in the 1990s was initiated by an oral and maxillofacial surgeon, Howard Israel, who together with medical historian and physician, Bill Seidelman, motivated *Yad Vashem* (the Israel Holocaust and Martyrs Remembrance Authority) to send an official inquiry on the historical background of the atlas to the University of Vienna.^{72,79,80} The subsequent investigation revealed that Pernkopf, as Dean of the university, was involved in the removal of all faculty members, who were of Jewish origin or political opponents.^{81,82}

In that same year, the University of Vienna responded by admitting to a systematic suppression and denial of the Nazi past in the anatomy department,⁸³ and thereby commissioned the *Senatorial Project of the University of Vienna*.⁸⁴ The historic research project ascertained that the Vienna Anatomical Institute received 3,964 unclaimed bodies; 7 willed body donations; approximately 7,000 bodies of fetuses, still born babies, and children (all dead from natural causes); and at least 1,377 bodies of executed persons executed after civilian and military trials in the Vienna court system, including 8 persons of Jewish origin. It remained unclear exactly which bodies were used for the creation of the atlas images produced during the Nazi period. These significant findings sparked an ethical controversy surrounding the handling of Pernkopf's atlas,⁸⁴⁻⁸⁶ including removal or transition of Pernkopf's atlas into special collections by medical libraries, and inclusion of a historic note of disclosure.^{87,88} The ethical dilemma regarding its use relates to larger issues surrounding data derived from Nazi science, such as the Dachau hypothermia experiments,^{89,90} and the effects of phosgene gas in concentration camps.⁹¹ Nonetheless, Pernkopf's atlas persists in circulation in the medical community, however, ethical considerations in its use for

surgery and education have not been documented. To start such a documentation, the current role of the atlas in surgery and diffusion of innovation has to be assessed.

DIFFUSION, DISSEMINATION, AND IMPLEMENTATION

1

Diffusion of innovation was proposed by Everett Rogers in 1962 as a general process of social change, where an idea or innovation is passively spread by members of a social system through existing channels.⁹² This process routinely takes many years to gain widespread adoption. Rogers defined five categorical groups of individuals in diffusion theory, each with distinct roles relating to the “circle of local peer networks.” *Innovators* are outside the peer network, which frees them from constraints of a local system and allows them to generate new ideas. *Early adopters*, being well-respected within the local system, are the first to accept a new idea. These individuals typically have the resources and risk tolerance to try new ideas. In healthcare, they are commonly elected leaders or representatives of clinical groups. As their status decreases the uncertainty and risk of this idea, an *early majority* will adopt and embrace innovations. Once adoption has reached 15-20% of members (i.e. “tipping point”) in the local system, the idea spreads rapidly to the rest of the system, including the *late majority* and the *laggards*, who are considered suspicious and/or resistant to change (Fig. 1.1).

Indeed, studies that have investigated the neuroscience basis of learning, indicate we are hardwired to resist change and seek safety in consistency and predictability.^{93,94} If a new idea is not communicated to and endorsed by *early adopters*, the innovation will be rejected and fails to achieve widespread adoption. This spontaneous and passive process generally takes time. For example, treatment and prevention of scurvy with Vitamin C took over two centuries to be accepted.⁹² Another analogy is the time it takes in the rise and fall of a surgical technique, known as Scott's parabola (Fig. 1.2).⁹⁵ Furthermore, there are two principles that affect the speed of adoption.⁹² The first is the perception of the innovation, or how well the innovation benefits with the values, beliefs, past history, and current needs of individuals, its complexity (simple ideas spread more quickly), its trialability (testing on a small scale), and its observability (adopters watching others performing the new innovation). The second principle involves the contextual system factors, such as communication, incentives, leadership, and management. For example, healthcare organizations that foster social exchanges between *innovators*, *early adopters*, and *early majority* will see faster diffusion than organizations that discourage it.

In the years following the introduction of diffusion theory, focus has shifted to means of improving the spread and adoption of new ideas.^{96,97} Collectively, this research constitutes a new and upcoming area of study called dissemination and implementation (D&I) science, or known as research translation,⁹⁸ knowledge translation,⁹⁹ knowledge-to-action,¹⁰⁰ evidence-based policy and practice,¹⁰¹ and implementation research.^{102,103} This inconsistency in terminology can create confusion, but experts agree that they all focus on the active, directed, and planned spread of ideas.¹⁰⁴ It promises to improve the speed of safe translation of medical research knowledge into widespread clinical practice, and to narrow the quality and disparity gap in

FIGURE 1.1. Diffusion of innovation. The bell-shaped curve describes the diffusion of innovation across the social groups of innovators, early adopters, early majority, late majority, and laggards. The S-curve describes the percent of adoption across these social groups. The tipping point occurs when an idea reaches 15-20% of adoption in the local system, essentially transitioning into the early majority, after which, there is rapid “unstoppable” adoption in the group. Modified from Rogers EM. *Diffusion of Innovations*. 5th ed. New York, NY: Simon and Schuster; 2003.

FIGURE 1.2. Scott's parabola. If the S-curve of adoption is extended to represent when an idea falls into disuse, the curve becomes what is known in surgery as Scott's parabola – the rise and fall of a surgical technique. Roger's diffusion of innovation is considered the first ½ of Scott's parabola. Modified from Scott JW. Scott's parabola. BMJ. 2001;323:1447.

healthcare (Fig. 1.3).¹⁰⁵ There are two interrelated and separate components of D&I research: (1) *dissemination science* – the study of how knowledge and interventions can best be communicated to potential adopters, and (2) *implementation science* – the study of how an intervention is actually integrated into practice.

In general, approaches in D&I science involve (1) an evidence-based intervention to be scaled or introduced to a new patient population, (2) planned strategies for dissemination and implementation of the intervention, (3) validated approaches to evaluate the implementation of the intervention, and (4) practices to ensure its sustainability.¹⁰⁶ Rather than relying on intuition or trial-and-error, D&I science builds and utilizes validated models, often referred to as frameworks or theories, to achieve these aims. Characteristics of individuals and settings (inner and outer) are important to examine as described in a commonly-used consolidated framework for implementation research.¹⁰⁷ Specifically, inner-setting involves understanding hospital resources, organizational culture for acceptance and change, or relationships between physicians, patients, and administrators. Assessing outer-setting may include how a surgical department interacts with the greater international, or patient community. Lastly, characteristics of individuals may refer to how surgeons view their responsibility to follow ethical practices.

Popular frameworks include RE-AIM, translation research continuum or ‘T’ models, knowledge-to-action (KTA), promoting action on research implementation in health services (PARiHS), and others.⁹⁸ RE-AIM was created as a 5-step framework (reach, efficacy, adoption, implementation, and maintenance) to conceptualize public health impact of an intervention.¹⁰⁸ It was later modified to introduce effectiveness to efficacy to improve its generalizability,¹⁰⁹ and included individual and organizational levels for each step to better account its local context.¹¹⁰ The ‘T’ models was first proposed through the National Institutes of Health Roadmap to acknowledge the translational steps required for benchtop research to be applied in clinical practice.⁹⁸ These steps included T0 (description and discovery),¹¹¹ T1 (basic science to clinical research), T2 (clinical research to clinical practice),¹¹² T3 (clinical practice to large-scale dissemination),¹¹³ and T4 (large-scale dissemination to population health outcomes).¹¹⁴ Others have made adaptations to the model to become circular rather than linear.¹¹⁵ While RE-AIM easily outlines the criteria for the successful implementation of an intervention, the ‘T’ models depict a pathway in medical research from ideation to implementation.¹⁰⁷

Having a keen understanding on how new ideas or innovations naturally diffuse in a social system and the active process to disseminate and implement these ideas into practice, promises to narrow the quality and disparity gap in healthcare (Fig. 1.4). While the IDEAL framework provides a staged roadmap to develop and evaluate surgical procedures,³⁶ it lacks an active process to safely accelerate the adoption of surgical innovation. Implementation science emphasizes the spread and adoption of new ideas,^{96,97} where knowledge is shared from the *innovators* to the *early adopters*. *Innovators* could also be considered as experts or key-opinion leaders in their social system. Before an active framework to translate expertise can be considered, we must first review the current research in expertise.

FIGURE 1.3. Implementation and deimplementation. The field of dissemination and implementation promises to speed the adoption of innovation, essentially reducing the time for surgeons to adopt a new technique. This aims to truncate the timeline of Roger's parabola for diffusion of innovation and the first ½ of Scott's parabola with the rise of a surgical technique. A new subfield within D&I (deimplementation) studies the process of when innovation falls into disuse, promising its quick and safe exit, and thereby making room for the next innovation. This aims to truncate the timeline of the second ½ of Scott's parabola with the fall of a surgical technique.

EXPERT PERFORMANCE

Expert performance is an approach introduced by Anders Ericsson that proposes to identify superior performance, capture it, and reproduce this performance towards achieving a state of mastery.¹¹⁶ This approach differs from mastery learning, which describes students reaching defined learning goals within a sequential curriculum of increasing difficulty.¹¹⁷ The accurate measurement of performance provides an opportunity to identify areas for improvement. With knowledge of how to specifically improve through practice, learners can work towards changing the cognitive processes. When this process is supervised and guided by a teacher or coach, it is called *deliberate practice*, which is defined as individualized training activities specifically designed for performance improvement and successive refinement.^{118,119} Most notably, this practice formed the basis for the “10,000-hour rule” to become an expert.

Deliberate practice and the acquisition of expert performance has been well-documented in domains with competition such as sports, dance, music, and chess.¹¹⁶ In chess, the most extensively researched domain of expertise, research has revealed a small number of critical moves that clearly distinguishes superior players from those with lower chess ratings.¹²⁰ Furthermore, an elite level of performance in violinists was attributed to the amount of time spent in performing solitary and *deliberate practice*.¹¹⁸ Identifying individuals with reproducible superior performance in these domains is relatively simple compared to measuring expertise in medicine and surgery which involves the complexity in treating patients.¹²¹ While objective performance in medicine and surgery can be measured through patient outcomes, this requires collecting and analyzing the necessary amount of long-term outcome data.¹²² This can include measuring performance through pre- and post-ratings by treated patients or patient satisfaction ratings of outcomes.^{123,124}

The development of expertise is proposed to occur through a gradual sequence of states with three distinct types of representations.¹²⁵ The first type is a mental representation that allows an individual to imagine their performance that they want to attain. For example, expert musicians imagine particular sounds while playing a score or surgeons envision their operative performance during dissection. The second type of representation is to translate the desired image into actions, specifically the actual performance. The third and final representation is the perception or feedback of their performance, such as expert musicians listen to their performance to identify discrepancies between the aspired and actual expression of music. In surgery, when encountering abnormal anatomy during a routine procedure, technical adjustments can be made to return to the envisioned steps. A practice of expertise is the ability to envision how an operation will flow and to identify potential knowledge deficiencies to improve upon.^{126,127} As expertise is attained, the sequence of states and the individual representations becomes more distinct with increased complexity, refinement, and inter-connectedness. *Deliberate practice* is shown to enhance or reduce the periods of graduated sequence of states, therefore highlighting its relationship with performance.¹²¹

A common perspective in expertise is that experts have automated their performance.^{128,129} Research has shown that experts recognize patterns, rather than engage in thinking, while extracting more useful and reportable information about a specific situation. In traditional cognitive learning theory, the process of skills acquisition occurs through the dual process model which describes two systems of thinking: (1) system 1 thinking, which is fast, low effort, and often subconscious and (2) system 2 thinking, which is slower and requires conscious effort.^{130,131} Within this framework, it is known that novices in any discipline use system 2 as they acclimate to their discipline, whereas experts rely more heavily on the automated processing of system 1 to make decisions. In surgery, a study investigating of situational awareness has demonstrated that experienced surgeons are more skilled in accessing the ideal mental representation of information relevant to the current state of surgery.¹³² Additionally, the need to monitor this mental representation during critical situations is based on observing surgeons with successful or unsuccessful outcomes. An analysis of surgical errors during laparoscopic cholecystectomy revealed that bile duct injuries were due to the misperception of anatomical structures rather than technical errors, thereby indicating inadequate mental representation.¹³³ These findings support the automatic processing by experienced surgeons, where superior performance is associated with refined representations to plan, execute, and monitor surgical states.^{121,125} Developing educational interventions to promote this system of skills acquisition may promote expertise.

Applying the theoretical framework of expert performance and *deliberate practice* to surgery is not obvious. While chess and patient management scenarios allow for open-ended answers to study expertise, physicians construct key-feature problems for managing patients, which are then validated through a consensus.¹³⁴ To incorporate the expert-performance approach in medicine, we must first examine medical training and the role of continued medical education (CME) and professional development (CPD) in the longitudinal progression of expertise (Fig. 1.5).

Training in medicine has traditionally focused on first acquiring theoretical knowledge and then clinical experience during clerkship, where students begin to make decisions about specializing. The focus on knowledge and neglect of gradual skill acquisition is exemplified by the well-known adage, "See one, do one, teach one," for learning and performing medical procedures.¹³⁵ Specialization is then carried into residency training, which in surgery, is based on Halsted's apprenticeship model using an 80-hour workweek.¹³⁶ Halsted incorporates three principles for surgical training: (1) residents must have intense and repetitive opportunities for patient care under the supervision of a skilled teacher, (2) residents must acquire an understanding of the scientific basis of disease, and (3) residents must acquire skills in patient management and technical operations of increasing complexity with graded responsibility and independence.¹³⁷ Surgical fellowships provide additional opportunities to refine specialization. An argument can be made that graduated surgeons are at a peak of knowledge, having finished training at teaching hospitals which are considered frontiers for innovation. Performance, on the other hand, is a life-long practice for improvement; reduction of operative errors being a function of the number of completed procedures.¹³⁸ Despite the apprenticeship model and trends

FIGURE 1.5. Knowledge gap in surgical education. Surgical innovation occurs over a period of time and parallels the expertise at its host training institution. Surgeons will progress through their training, attaining expertise and best practices at their host training institution. As they graduate and, especially if they enter independent practice, their knowledge plateaus depending on their level of engagement with the standards of care. We define a master surgeon as an individual, who is a pioneer at the frontier of innovation, that demonstrates clinical and technical excellence and is also an avid educator with a purpose and availability to translate their knowledge to others. A video-based learning (VBL) program designed to translate the expertise of these master surgeons into practice could close the knowledge gap between surgeons-in-practice and the rate of surgical innovation.

towards competency-based training,¹³⁹ major challenges exist during the transition from residency to independent practice.¹⁴⁰ Accurate assessment of knowledge and skills, mentoring, and use of new learning technologies have been recommended for individuals entering practice.

The pace of surgical innovation continues irrespective of training and practice demands, therefore creating a knowledge gap for surgeons in practice (Fig. 1.5). To keep up to date, surgeons attend national meetings, interpret new discoveries from published peer-review literature, and participate in decentralized CME activities.¹⁴¹ CME and maintenance of certification (MOC) were designed to address this knowledge gap. However, a 2010 report by the National Academy of Medicine (NAM) identified irreconcilable flaws in the current approach to CME, concluding that it “fails to deliver the most useful and important health information to health professionals, leaving them unable to adopt evidence-based approaches.”¹⁴² A review also demonstrated that attending CME lectures did not provide any meaningful changes in physicians’ actual practice.¹⁴³ The report called for a transition away from CME and towards a system of CPD, which emphasizes long-term practice change. Several recommendations included (1) facilitating self-directed learning outside of professional activities, (2) using learning theories to develop educational interventions, (3) analyzing the effectiveness of these interventions, and (4) improving the

value and cost-effectiveness of continuing education. Online multimedia was highlighted as a promising strategy for CPD, since it is inexpensive, highly accessible and allows physicians to learn at their own pace.¹⁴⁴ A shift from MOC to continuous certification is occurring to address the deficits in CME and make the process of certification more relevant, cost-effective, and convenient to participate.¹⁴⁵

To implement the expert-performance approach in surgery, Ericsson proposes to identify superior performance, study performance, and create training methods to develop cognitive representations associated with expertise.¹²⁵ Not only do individuals with superior performance demonstrate proficient clinical reasoning and technical skills, these individuals could be considered key-opinion leaders or pioneers, who have developed a distinguished reputation for clinical excellence and teaching. A clear relationship between gradual improvement of patient outcomes and surgeons' experience indicate individuals with expert performance are late in their careers. Less experienced surgeons, who have completed fewer than 10 procedures, were twice as likely to have patients with cancer reoccurrence, as compared with experienced surgeons with more than 250 completed procedures.¹²² Additionally, surgeons with superior performance are associated with reduced risk of injuring adjacent tissues, ducts, and vessels when identifying anatomical structures during laparoscopic procedures.¹³³ The American Association of Plastic Surgeons awards the "Clinical of the Year" to recognize significant clinical achievement and the results of treatment in a major area of clinical interest. By having experienced surgeons, like these distinguished clinicians, develop training methods to provide technical and optimal strategies to overcome common pitfalls based on several decades of experience, less experienced surgeons may improve their outcomes or reduce their rate of complications.

The second part of expert-performance is to examine operative performance, which can be accomplished by video-recording for the purpose of assessment or training.¹⁴⁶ Systematic video recording of surgeries can be followed by detailed analysis,¹⁴⁷ and even processed using computer vision and machine learning to automatically generate operative steps in laparoscopic sleeve gastrectomy.¹⁴⁸ Operative room videos have also been continuously captured and synchronized with several sources of intraoperative data to create a "black box" for quality improvement.^{149,150} This technology can be used to identify factors that contribute to adverse events, implement targeted interventions, and improve patient safety. Educational coding schemes have been developed to study communication amongst the surgical team, which is then used to identify technical problems in trainees to receive accurate feedback for improvement.¹⁵¹⁻¹⁵⁴ In a pivotal study involving video-recording, Birkmeyer and colleagues discovered that post-hoc ratings of videos and complication rates in bariatric surgery were related, thereby demonstrating a quartile of surgical skill in practicing surgeons.¹⁵⁵ This study suggests that training surgeons to increase their skill will reduce complication rates, and supports the use of surgeons in the upper quartile of performance to generate training models associated with expertise.

The final part and key component of expert-performance is to establish training methods that facilitate cognitive representations of expertise in learners. Ericsson

postulates that surgeons can review video recordings prior to operating, to extract important information to improve operative performance,¹⁴⁶ and to establish a mental state of surgical flow which promotes remaining attentive during automaticity.¹²⁷ A review of simulation learning describes simulator-trained surgeons perform better when tested on animal models and human simulators that lack complicating factors.¹⁵⁶ While proven beneficial, this type of training was not designed to facilitate superior performance or *deliberate practice* for surgeons in independent practice.

Providing feedback on operative performance is a known training method to accompany simulation for acquiring fundamental techniques.¹⁵⁷ In this study, inexperienced surgeons were trained to perform a laparoscopic cholecystectomy using a simulator, and then offered to receive feedback on their deficits or to watch tutorials unrelated to the procedure. Trainees who received feedback and performed *deliberate practice* attained higher quality of performance. These findings, along with many similar studies,^{152,158} led to the development of the new field of surgical coaching, which is providing feedback during peer coaching sessions for technical skills (psychomotor), cognitive skills (decision-making), non-technical skills (communication), and stress management (coping strategies).¹⁵⁹⁻¹⁶² While feedback is a promising area to explore, an effective training method designed to promote expertise during independent practice has not been established. In this thesis, expert-performance approach was implemented in surgery by (1) identifying surgeons with superior performance and (2) video-recording their performance, to (3) produce high-quality training methods for practicing surgeons and trainees.

EXAMPLE-BASED LEARNING AND COGNITIVE LOAD THEORY

Learning from example is an evolutionary efficient process to borrow knowledge from a person's own experience, reorganize it into their own existing knowledge, and use it for their own purpose.¹⁶³ The "borrowing and reorganizing" principle in example-based learning, also known as observational learning outside the domain of educational research,¹⁶⁴ differs from traditional problem-based learning used in student-centered pedagogy which emphasizes learning through the experience of solving open-ended problems.¹⁶⁵ Example-based learning has been studied from two different perspectives: (1) cognitive research which has focused on *worked examples* – the process of providing learners with a written account of how a problem can be solved, and (2) social-cognitive research which has focused on *modeling examples* – the process of observing from others.¹⁶³

In cognitive research, studies are consistent in that novice learners rely heavily on studying *worked examples* for instructions, which is more effective and efficient for learning with improved outcomes and less time investment than problem-solving.^{166,167} This is known as the "*worked example effect*" and is explained by different cognitive processes implored by problem-solving and example study.¹⁶⁷ *Worked examples* allow a learner to devote cognitive capacity to study a solution's procedure by constructing a cognitive representation (*cognitive schema*).¹⁶⁴ These examples

can be used as an analogy for problem-solving, either by referencing physical or mental examples during problem-solving.¹⁶⁸ Furthermore, *worked examples* can be abstracted from examples, which enables learners to solve similar problems and transfer these skills for other solutions.¹⁶⁹⁻¹⁷³

In social-cognitive research, the effectiveness of *modeling examples* is not usually compared with other types learning, but explained through the general cognitive processes required for observational learning.¹⁶³ Observers acquire the *cognitive schema* of a model's behavior that can outlast the learning activity and enable learners to replicate this behavior at later occasions.^{174,175} This compliments findings that observational learning can occur without imitation taking place.¹⁷⁶ Acquiring *cognitive schema* requires the learner to pay attention to relevant aspects of the model's behavior, specifically, selective attention is a necessary subfunction in observational learning.¹⁷⁵ Moreover, this attained information needs to be encoded in memory through a mechanism which the information is actively integrated with the learner's existing knowledge, and not through one-on-one mapping.^{164,167,174,175} Mental or physical rehearsal has an important role in retention and performance.¹⁷⁵ While learners may not always be able to reproduce the observed behaviors, this depends on the quality of the acquired *cognitive schema* and to the extent at which learners have mastered the skill.¹⁶³ Another factor that affects the effectiveness of modeling behavior includes learner motivation.¹⁷⁷ Both cognitive and social-cognitive research stress the importance of constructing an appropriate, high-quality *cognitive schema* to guide effective learner performance.

Modeling examples is widely accepted and used to teach psychomotor skills.¹⁷⁸ Research on the mirror neuron system revealed the underlying mechanisms for observational learning – demonstrating that the same neural circuits involved in the execution of a motor action, also respond to observing someone else execute that same action.¹⁷⁹ These same neural circuits of observing and executing motor actions are active when hearing a description of such actions,¹⁸⁰ or mentally rehearsing such actions.^{181,182} These findings describe a physiological mechanism in using examples to learn a wide range of skills.

There exist several factors that can increase and decrease the effectiveness of learning from example, which include learner characteristics and the design and delivery of an intervention. One of the most important characteristics is the learner's prior knowledge of the task. Research on the "expertise reversal effect" revealed that high level of instructions provided by *worked examples* to learners, who have already developed a *cognitive schema*, are ineffective or even detrimental to learning.^{183,184} With respect to *modeling examples*, Bandura empathized that a modeling behavior that is too complex for a learner may result in fragmentation of learning.¹⁸⁵ These studies highlight the importance to adapt the learning intervention to the learner's level of knowledge.

Before describing how instructional design can affect learning, cognitive load theory (CLT) needs to be explained along with the processes that encourage acquisition of knowledge. CLT was developed in 1988 from a study of problem-solving by

John Sweller,¹⁸⁶ and its design principles and strategies was later incorporated in health professions education.¹⁸⁷ CLT suggests that learning occurs through a human cognitive architecture where information is captured from a sensory process, transferred to limited-capacity working memory, and then encoded in high-capacity long-term memory.¹⁸⁸ Learning is dependent on how well the limited-capacity of working memory is managed.

There are three types of cognitive load that contribute to the quality of information learned and design of the instructions: intrinsic load, extraneous load, and germane load.¹⁸⁸ Intrinsic load is defined as the intrinsic nature of the learning tasks or the complexity of the material presented relative to the learner's expertise. For example, a novice who has never performed a particular skill will have high intrinsic load occupying the working memory while learning the skill compared to an experienced individual. Unlike intrinsic load, extraneous load is imposed by the instructional procedures. For example, in video-based studies, poor video quality or the need to simultaneously read text and watch the video would contribute extraneous load to the working memory. Finally, germane load refers to the working memory resources used to handle intrinsic load, essentially the work of learning. While developing a *cognitive schema*, germane load is often optimized by increases in intrinsic load that does not result in overload of the working memory. Prompting learners to explain or reflect upon the presented materials are examples of optimizing germane load. Designing learning interventions to address intrinsic, extraneous, and germane loads are the basis of many studies on effective instructional design.

Early research revealed that the design of an example played an important role in determining the effectiveness of *worked examples*.¹⁸⁹ This led to instructional design guidelines, such as avoid splitting attention by integrating mutually referring information (text and images),¹⁹⁰ and avoid redundancy where information should only be presented once.¹⁹¹ Stimulating more active processing of the examples, like emphasizing important aspects of a procedure, helps learners understand the underlying rationale of a procedure and facilitate knowledge acquisition.^{172,192} However, this design may become redundant quickly and should be faded out.¹⁹³ Implementing learning points has been effective in teaching conflict management skills in video-based *modeling examples*.¹⁹⁴ In addition, cognitive rehearsal or imagination of an observed behavior can enhance learning,¹⁹⁵ provided that it is accurate and obtained with materials that are high in intrinsic load.¹⁶⁷ A review of design principles for instructional animations describes the importance to verbally guide learners through examples, which is known as cuing or perceptual highlighting.¹⁹⁶

Lastly, the delivery of a learning intervention determines the effectiveness of learning from example. In support of Ericsson's concept of *deliberate practice*,¹⁹⁷ Bandura originally indicated that giving an opportunity to practice the observed behavior between modeling activities fosters learning.¹⁷⁵ Indeed, this method, described as example-problem pairs, were shown to be more effective than problem-solving only.¹⁹⁸ Presenting problems before examples, problem-example pairs, allowed learners to note deficiencies in their own performance, however this was less effective than example-problem pairs.¹⁹⁹ An effective delivery strategy that accounts

for a learner's experience is to present problems with increasingly more complex steps, also known as fading.²⁰⁰ No overall differences were found between fading, problem-example pairs, and example-problem pairs in computer-based instructional modules.²⁰¹ In summary, the method of delivery can affect learning from examples. These combined example studies that evaluate learner characteristics and the design and delivery of educational interventions, became the core principles of instructional design and can be implemented in multimedia or video-based learning in surgery.²⁰²

VIDEO-BASED LEARNING IN SURGERY

Video is an electronic medium used for the recording, playback, and display of visual media. A common phrase used to describe its value – “If a picture is worth a thousand words, then a video is worth a million,” or how Dimick and Scott describes it – “A video is worth a thousand operative notes.”³⁸ The earliest-known film of surgery was performed by French cameraman Eugenio Py in 1899, who captured a patient being anesthetized to undergo a lung hydatid cyst removal.²⁰³ Film became digital in 1986 when Sony commercially introduced the D1 format, which recorded an uncompressed component video signal in a digital format. It was not until the late 2000s, that the video technology exploded into mainstream use when recording solutions became more accessible and cost-effective, along with editing software and online publishing channels. *YouTube* was founded in 2005 and would become the largest video-sharing website to usher in a new wave of content, which included short video clips, music videos, documentaries, movie trailers, video blogging, and educational videos.

Salman Khan popularized educational videos by uploading highly engaging “white-board” videos teaching mathematics to *YouTube*, receiving more than 458 million views in the first several years. *Khan Academy* launched in 2008 as an open-access educational organization using videos to teach science, technology, engineering, and mathematics (STEM) to students. Leveraging their experience in videos and learning, Prober and Khan proposed a new model for medical education based on the “flipped classroom” design,²⁰⁴ where students would prepare for class by watching short lecture videos, thereby allowing time in the classroom to be spent exploring topics in greater detail through discussion.²⁰⁵ Students could re-watch lectures and digest materials at variable playback speeds to improve efficiency. Surgery and the culinary arts share similar training models, being based on apprenticeships and intense workweeks.²⁰⁶ *Rouxbe* was founded in 2005 as an online culinary school using professionally-filmed, high-quality videos to teach culinary skills and cooking techniques. With these technologic developments in other industries, it was only time before video became an essential part of surgery – to report outcomes, evaluate performance, and learn new techniques.

YouTube has become the most frequently used source for educational videos in preparing for surgery,²⁰⁷ however there is concern over the reliability and educational value of the videos.²⁰⁸ This concern led to a series of systematic reviews assessing content quality on *YouTube* in several surgical specialties and the anatomical

sciences,²⁰⁸⁻²¹⁵ each concluding substantial variability in educational value due to nonuniform production quality, unclear intent, and lack of a peer-review process. Several studies have examined methods for recording videos in open surgery to assess surgical skill and improve production quality.²¹⁶⁻²¹⁸ In response to these issues, a LAP-VEGaS consensus statement offered 37 guidelines to standardize and improve the educational quality of videos in laparoscopic surgery.²¹⁹ A subsequent editorial emphasized the need to optimize videos for learning by managing cognitive load, tailoring content to different levels of expertise, maximizing audience engagement, and limiting video duration.^{202,220} Only one study in medicine, performed by Lau and colleagues, used learning analytics to document viewing patterns in ten lecture videos describing electroencephalography interpretation by a single author.²²¹ Along with other studies examining massive open online courses, their findings depicted a decline in viewing engagement with increasing video duration,^{222,223} thereby supporting the notion that educational videos should be less than 10-minutes.²⁰⁴ Despite the fact that surgeries vary greatly in time and complexity, surgeon engagement in educational videos have not yet been studied, along with factors influencing preferred video duration.

The journal – *Medical Teacher*, has a popular series to provide practical advice in the form of “Twelve Tips.” To improve the quality of educational videos, experienced authors have published 12 tips for the effective use of videos in medical education,²²⁴ production of digital chalk-talk videos,²²⁵ reducing production time and increasing long-term usability of instructional videos,²²⁶ and improving the effectiveness of web-based multimedia instruction for clinical learners.²²⁷ These papers drew conclusions from the cognitive theory of multimedia learning (CTML), which analyzed medical animations to describe evidenced-based principles for managing cognitive load and enhancing knowledge acquisition.²²⁸ In this study, Yue and colleagues recommended principles to manage essential processing (preempting learner), minimize extraneous processing (synchronizing audio-video cues), and facilitate generative processing (embedding features to control learning). Rachel Ellaway constructed similar principles by defining a framework for e-learning research to evaluate external, internal, implementation, and user experience factors.²²⁹ Ellaway and colleagues would later define their experience on the *PocketSnips Project* – creating a series of short clinical skills videos to be used as “reusable learning objects” and selecting YouTube as a publishing platform.²³⁰ While educators have explored methods in producing high-quality content based on the CTML, the efficacy and effectiveness of video-based learning has not been explored in surgery, nor have the technical requirements been defined in the instructional design of a video platform that preempts learning, reduces extraneous user interactions, and allows users to control the learning environment.

The evaluation of the effectiveness in learning surgical skills through videos is based largely on laparoscopic simulation studies, where a video monitor is required to visualize and perform surgery. Indeed, simulation-based laparoscopic training has large benefits when compared with no intervention and is moderately more effective than non-simulation instruction.²³¹ In cleft lip and palate surgery, which involves complex manipulation of anatomical flaps for reconstruction, 3D digital sim-

ulation have demonstrated applications in preoperative planning and performing surgery.^{232,233} In a prospective, randomized study examining surgical trainees, digital simulation training significantly improved operative knowledge, confidence, and performance when compared to textbook learning.²³⁴ Specifically, intraoperative video recorded by a smartphone was used to illustrate techniques, and was presented secondary to the animations of cleft lip surgery. Nevertheless, developing high-fidelity animations can be cost-prohibitive, especially to illustrate anatomically accurate landmarks and new techniques or innovations in nerve surgery. By incorporating the high-definition and 4K resolution standards of professional video and using a proposed method for video production to accommodate different types of learners, this visual medium may be a cost-effective approach to learning surgical skills once its role is clearly defined.

Learning clinical reasoning is an integral part of surgery – it encompasses all phases of patient management, from initial workup to post-operative care and follow-up.²³⁵⁻²³⁷ Both technical expertise and clinical reasoning are necessary for achieving optimal quality of care and outcomes.²³⁸ Several educational studies have used e-learning modules and interactive video lectures to promote knowledge transfer and retention in medical trainees and healthcare professionals alike.²³⁹⁻²⁴² Cheung and colleagues demonstrated the importance of knowing “why” and knowing “how” for the cognitive integration of procedural skills.²⁴³ In this randomized stimulation-based study, medical students who received a step-by-step video of a lumbar puncture with integrated “why” explanations were associated with improved conceptual knowledge and skill retention. Explaining the “why” is normally presented as a short preface to learning a procedure in many educational videos and lectures. However, this material is often overlooked, and learners can miss critical details important for the safe diffusion and adoption of new techniques. Separating the “why” as its own video to emphasize the topic may promote implementation of new practices.

Educational studies in surgery have mostly examined novel ways to enhance technical performance,²⁴⁴ however, comparatively little attention has focused on the means of teaching clinical reasoning.²⁴⁵ In general, online educational modules or video lectures are taught using voiced-over slides presented in a linear fashion. An alternative approach, supported by the CTML, is to create dynamic presentations using spatial contiguity,²⁴⁶ or diagrams and concept maps of information used to facilitate spatial learning.²⁴⁷ New developments in presentation software offer instructors the ability to illustrate materials on a visuospatial canvas and implement slide transitions to empathize spatial contiguity.²⁴⁸ Although, Hyll and colleagues have explored the software as an effective e-learning tool to compliment blended learning in medical student education,²⁴⁹ converting this style of presentation into engaging videos may be a novel approach of teaching clinical reasoning to practicing surgeons. In summary, this thesis will explore the development of an effective video platform and the role of video-based learning in the acquisition of surgical skills and clinical reasoning.

OUTLINE OF THESIS

The aim of this thesis is to develop an educational framework for the translation of expertise and dissemination and implementation of surgical innovation by (1) establishing video-based learning as an approach to learn operative skills and clinical reasoning in surgery, and (2) addressing the related ethical implications in the anatomical sciences. The hypothesis is that by incorporating the expert-performance approach with principles in cognitive theory of multimedia learning, videos can become an effective and equitable tool in surgery to adopt best practices when technical skills and clinical reasoning are taught separately. Additionally, thoughtful instructional design can influence the iterative development of a video platform to include learning analytics, which in return promotes the creation of high-quality content and user adherence to a captivating learning environment. During this journey, ethical issues may rise from surgical innovation and education. An approach is described to address ethical issues encountered in surgery and the anatomical sciences.

1

PART I: ESTBALISHING VIDEO-BASED LEARNING IN NERVE SURGERY

Video-based learning is a promising approach to disseminate and implement expert techniques and innovations in surgery. Nerve surgery is a new, modern specialty that has experienced shifts in reconstructive paradigms from nerve repair, to grafting, and to transfer.¹⁷ Because this subspecialty includes a heterogenous patient population that require diverse applications of innovative techniques, the role of video-based learning in nerve surgery is examined as a new and equitable model to share best practices and improve quality of care in surgery.

In **Chapter 2**, 6-years of experience is described developing an online education resource and producing over 100 educational videos in nerve surgery, which in turn evolved into a video-based learning platform and program that leverages learning analytics to guide content creation and educational interventions. The use of variable-duration surgical videos (short and long) is presented to target different types of learners and establish a reference for surgeon engagement. The educational program's outcomes are reported through the creation of an international surgeon viewership across 165+ countries by using the expert-performance approach. In **Chapter 3**, the role of surgical videos in improving operative performance and reducing errors is determined in a cadaveric stimulation-based study where residents perform a carpal tunnel release. In **Chapter 4**, a video-based module to teach clinical reasoning in surgery is presented by using knowledge assessments to describe electrodiagnostic indications for cubital tunnel surgeries. Surgeon practice change and adoption of a new surgical technique (supercharge nerve transfer) are reported.

PART II: ADDRESSING ANATOMICAL ETHICS IN SURGICAL INNOVATION

An ethical issue was encountered during the design of our video-based model to address learning curves and use anatomical illustrations to accompany the videos and teach technical skills in surgery. This involved Pernkopf's atlas of human anatomy which is considered a unique piece of science and art, depicting detailed illustrations of meticulous anatomic dissections, however, sourced from victims of the Third Reich. In **Chapter 5**, the "use" or "not to use" the Pernkopf atlas is assessed in nerve surgery and oral and maxillofacial surgery concerning disclosure, bioethical and religious considerations, and remembrance. In **Chapter 6**, an ethical framework is presented to address the use of Pernkopf's atlas in surgery which includes a responsum derived from Jewish law that is based from the *Vienna Protocol* and the principle of *pikuach nefesh*, the "saving of human life."

In **Chapter 7**, the findings of this thesis are summarized and discussed.

REFERENCES

1. Rogers WA, Lotz M, Hutchison K, Pourmoslemi A, Eysers A. Identifying surgical innovation: a qualitative study of surgeons' views. *Ann Surg.* 2014;259(2):273-278.
2. Wilson CB. Adoption of new surgical technology. *BMJ.* 2006;332(7533):112-114.
3. Hamilton D. *A History of Organ Transplantation: Ancient Legends to Modern Practice.* Pittsburgh, PA: University of Pittsburgh Press; 2012.
4. Richling B. History of endovascular surgery: personal accounts of the evolution. *Neurosurgery.* 2006;59(5 Suppl 3):S30-38; discussion S33-13.
5. Wiebers DO, Whisnant JP, Huston J, 3rd, et al. Unruptured intracranial aneurysms: natural history, clinical outcome, and risks of surgical and endovascular treatment. *Lancet.* 2003;362(9378):103-110.
6. Tan A, Ashrafian H, Scott AJ, et al. Robotic surgery: disruptive innovation or unfulfilled promise? A systematic review and meta-analysis of the first 30 years. *Surg Endosc.* 2016;30(10):4330-4352.
7. Tamai S. History of microsurgery. *Plast Reconstr Surg.* 2009;124(6 Suppl):e282-294.
8. Bellini E, Grieco MP, Raposio E. A journey through liposuction and liposculpture: Review. *Ann Med Surg (Lond).* 2017;24:53-60.
9. Sterodimas A, De Faria J, Correa WE, Pitanguy I. Tissue engineering in plastic surgery: an up-to-date review of the current literature. *Ann Plast Surg.* 2009;62(1):97-103.
10. Kwasnicki RM, Hughes-Hallett A, Marcus HJ, Yang GZ, Darzi A, Hettiaratchy S. Fifty Years of Innovation in Plastic Surgery. *Arch Plast Surg.* 2016;43(2):145-152.
11. Diaz-Siso JR, Bueno EM, Sisk GC, Marty FM, Pomahac B, Tullius SG. Vascularized composite tissue allotransplantation--state of the art. *Clin Transplant.* 2013;27(3):330-337.
12. Longaker MT, Rohrich RJ. Innovation: a sustainable competitive advantage for plastic and reconstructive surgery. *Plast Reconstr Surg.* 2005;115(7):2135-2136.
13. Gurtner GC, Rohrich RJ, Longaker MT. From bedside to bench and back again: technology innovation in plastic surgery. *Plast Reconstr Surg.* 2009;124(4):1355-1356.
14. Chung KC, Swanson JA, Schmitz D, Sullivan D, Rohrich RJ. Introducing evidence-based medicine to plastic and reconstructive surgery. *Plast Reconstr Surg.* 2009;123(4):1385-1389.
15. Wang Y, Kotsis SV, Chung KC. Applying the concepts of innovation strategies to plastic surgery. *Plast Reconstr Surg.* 2013;132(2):483-490.
16. Berwick DM. Disseminating innovations in health care. *JAMA.* 2003;289(15):1969-1975.
17. Domeshek LF, Novak CB, Patterson MM, et al. Nerve Transfers - A Paradigm Shift in the Reconstructive Ladder. *Plast Reconstr Surg Glob Open.* 2019;7(6):e2290.
18. Kuhn TS. *The Structure of Scientific Revolutions.* 3rd ed. Chicago and London: University of Chicago Press; 1996.
19. Poppler LH, Ee X, Schellhardt L, et al. Axonal Growth Arrests After an Increased Accumulation of Schwann Cells Expressing Senescence Markers and Stromal Cells in Acellular Nerve Allografts. *Tissue Eng Part A.* 2016;22(13-14):949-961.
20. Saheb-Al-Zamani M, Yan Y, Farber SJ, et al. Limited regeneration in long acellular nerve allografts is associated with increased Schwann cell senescence. *Exp Neurol.* 2013;247:165-177.
21. Mackinnon SE, Novak CB. Nerve transfers. New options for reconstruction following nerve injury. *Hand Clin.* 1999;15(4):643-666, ix.
22. Woolsey G. The Surgery of the Nerves. In: Keen WW, ed. *Surgery: Its Principles and Practice.* Vol 2. Philadelphia and London: W. B. Saunders Company; 1911.
23. Ray WZ, Mackinnon SE. Management of nerve gaps: autografts, allografts, nerve transfers, and end-to-side neurorrhaphy. *Exp Neurol.* 2010;223(1):77-85.
24. Gomez-Amaya SM, Barbe MF, de Groat WC, et al. Neural reconstruction methods of restoring bladder function. *Nat Rev Urol.* 2015;12(2):100-118.
25. van Zyl N, Hill B, Cooper C, Hahn J, Galea MP. Expanding traditional tendon-based techniques with nerve transfers for the restoration of upper limb function in tetraplegia: a prospective case series. *Lancet.* 2019.
26. Mackinnon SE, Yee A, Ray WZ. Nerve transfers for the restoration of hand function after spinal cord injury. *J Neurosurg.* 2012;117(1):176-185.
27. Fox IK, Novak CB, Krauss EM, et al. The Use of Nerve Transfers to Restore Upper Extremity Function in Cervical Spinal Cord Injury. *PM R.* 2018.
28. Zheng MX, Hua XY, Feng JT, et al. Trial of Contralateral Seventh Cervical Nerve Transfer for

- Spastic Arm Paralysis. *N Engl J Med*. 2018;378(1):22-34.
29. Afshari FT, Hossain T, Miller C, Power DM. Salvage of cervical motor radiculopathy using peripheral nerve transfer reconstruction. *Br J Neurosurg*. 2019;33(3):315-319.
30. Dumanian GA, Potter BK, Mioton LM, et al. Targeted Muscle Reinnervation Treats Neuroma and Phantom Pain in Major Limb Amputees: A Randomized Clinical Trial. *Ann Surg*. 2019;270(2):238-246.
31. Cheesborough JE, Smith LH, Kuiken TA, Dumanian GA. Targeted muscle reinnervation and advanced prosthetic arms. *Semin Plast Surg*. 2015;29(1):62-72.
32. Mackinnon SE. Discussion: State-of-the-Art Techniques in Treating Peripheral Nerve Injury. *Plast Reconstr Surg*. 2018;141(3):711-712.
33. Mackinnon SE. *Neve Surgery*. New York, NY: Thieme Medical Publishers, Inc; 2015.
34. Masic I, Miokovic M, Muhamedagic B. Evidence based medicine - new approaches and challenges. *Acta Inform Med*. 2008;16(4):219-225.
35. Miller ME, Siegler M, Angelos P. Ethical issues in surgical innovation. *World J Surg*. 2014;38(7):1638-1643.
36. Hirst A, Philippou Y, Blazeby J, et al. No Surgical Innovation Without Evaluation: Evolution and Further Development of the IDEAL Framework and Recommendations. *Ann Surg*. 2019;269(2):211-220.
37. Andriani P, Cattani G. Exaptation as source of creativity, innovation, and diversity: Introduction to the special section. *Industrial and Corporate Change*. 2016;25(1):115-131.
38. Dimick JB, Scott JW. A Video Is Worth a Thousand Operative Notes. *JAMA Surg*. 2019.
39. Angelos P. The ethical challenges of surgical innovation for patient care. *Lancet*. 2010;376(9746):1046-1047.
40. Broekman ML, Carriere ME, Bredenoord AL. Surgical innovation: the ethical agenda: A systematic review. *Medicine (Baltimore)*. 2016;95(25):e3790.
41. Lee ZH, Reavey PL, Rodriguez ED, Chiu ES, Caplan AL. Ethical Issues in Aesthetic and Reconstructive Surgical Innovation: Perspectives of Plastic Surgeons. *Plast Reconstr Surg*. 2019;143(1):346-351.
42. Bernstein M, Bampoe J. Surgical innovation or surgical evolution: an ethical and practical guide to handling novel neurosurgical procedures. *J Neurosurg*. 2004;100(1):2-7.
43. Lee Char SJ, Hills NK, Lo B, Kirkwood KS. Informed consent for innovative surgery: a survey of patients and surgeons. *Surgery*. 2013;153(4):473-480.
44. Bowers N, Eisenberg E, Montbriand J, Jaskolka J, Roche-Nagle G. Using a multimedia presentation to improve patient understanding and satisfaction with informed consent for minimally invasive vascular procedures. *Surgeon*. 2017;15(1):7-11.
45. Moore FD. Ethical problems special to surgery: surgical teaching, surgical innovation, and the surgeon in managed care. *Arch Surg*. 2000;135(1):14-16.
46. Barnes RW, Lang NP, Whiteside MF. Halstedian technique revisited. Innovations in teaching surgical skills. *Ann Surg*. 1989;210(1):118-121.
47. Barkun JS, Aronson JK, Feldman LS, et al. Evaluation and stages of surgical innovations. *Lancet*. 2009;374(9695):1089-1096.
48. Gouma DJ, Go PM. Bile duct injury during laparoscopic and conventional cholecystectomy. *J Am Coll Surg*. 1994;178(3):229-233.
49. Huang SM, Wu CW, Hong HT, Ming L, King KL, Lui WY. Bile duct injury and bile leakage in laparoscopic cholecystectomy. *Br J Surg*. 1993;80(12):1590-1592.
50. Lepsien G, Ludtke FE, Neufang T, Schafmayer A, Peiper HJ. Treatment of iatrogenic common bile duct injury during laparoscopic cholecystectomy through the laparoscopic insertion of a T-tube stent. *Surg Endosc*. 1991;5(3):119-122.
51. Lujan JA, Parrilla P, Robles R, Marin P, Torralba JA, Garcia-Ayllon J. Laparoscopic cholecystectomy vs open cholecystectomy in the treatment of acute cholecystitis: a prospective study. *Arch Surg*. 1998;133(2):173-175.
52. Bass EB, Pitt HA, Lillemoe KD. Cost-effectiveness of laparoscopic cholecystectomy versus open cholecystectomy. *Am J Surg*. 1993;165(4):466-471.
53. Strasberg SM, Brunt LM. Rationale and use of the critical view of safety in laparoscopic cholecystectomy. *J Am Coll Surg*. 2010;211(1):132-138.
54. McCullough LB, Jones JW, Brody BA. *Surgical Ethics*. New York, NY: Oxford University Press; 1998.
55. Ferreres AR, Angelos P, Singer EA. *Ethical Issues in Surgical Care*. Chicago, IL: American College of Surgeons; 2017.

56. Kodner IJ. Ethics curricula in surgery: needs and approaches. *World J Surg.* 2003;27(8):952-955; discussion 955-956.
57. Kodner IJ. Surgeons and clinical ethics. *Surgery.* 2008;143(4):460-462.
58. Leitner A, Kodner IJ, Munson R, Cronin DC, 2nd. Collaboration with China in the field of organ transplantation. *Surgery.* 2008;144(5):725-728.
59. Grieselhuber NR, Kodner IJ, Brown D, Yu J. Confronting the therapeutic misconception. *Surgery.* 2017;162(1):183-187.
60. Luginbuhl RD, Kodner IJ, Keune JD. Conflicts of interest concerning the use of implants in the operating room. *Surgery.* 2010;147(5):738-741.
61. Means JM, Kodner IJ, Brown D, Ray S. Sharing clinical photographs: Patient rights, professional ethics, and institutional responsibilities. *Bull Am Coll Surg.* 2015;100(10):17-22.
62. Chen DY, Vuylsteke K, Kodner IJ, Brown D, Ray S. Physicians judging medical negligence: a conflict of values. *Surgery.* 2015;157(4):818-823.
63. Field MJ, Lo B. *Conflict of Interest in Medical Research, Education, and Practice.* Washington, DC: National Academies Press; 2009.
64. Mastroianni AC. Liability, regulation and policy in surgical innovation: the cutting edge of research and therapy. *Health Matrix Cleveland.* 2006;16(2):351-442.
65. Santosa KB, Larson EL, Vannucci B, et al. Gender Imbalance at Academic Plastic Surgery Meetings. *Plast Reconstr Surg.* 2019;143(6):1798-1806.
66. Bertelli JA, Soldado F, Rodrigues-Baeza A, Ghizoni MF. Transfer of the Motor Branch of the Abductor Digiti Quinti for Thenar Muscle Reinnervation in High Median Nerve Injuries. *J Hand Surg Am.* 2018;43(1):8-15.
67. Nichols CM, Brenner MJ, Fox IK, et al. Effects of motor versus sensory nerve grafts on peripheral nerve regeneration. *Exp Neurol.* 2004;190(2):347-355.
68. Vernadakis AJ, Humphreys DB, Mackinnon SE. Distal anterior interosseous nerve in the recurrent motor branch graft for reconstruction of a median nerve neuroma-in-continuity. *J Reconstr Microsurg.* 2004;20(1):7-11.
69. Hildebrandt S, Seidelman WE. Where do they come from? A call for complete transparency regarding the origin of human tissues in research. *ESMO Open.* 2017;2(2):e000201.
70. Williams DJ. Is a picture worth a thousand lives? The truth about the most beautiful book you will never see. The twenty-third annual Charles Henry Hackley distinguished lecture in the humanities.; May 20, 2004, 2004; Muskegon, Michigan.
71. Weissmann G. Springtime for Pernkopf. *Hosp Pract (Off Ed).* 1985;20(10):142-168.
72. Weissmann G. Origins of the Pernkopf anatomy atlas. *JAMA.* 1997;277(14):1122; author reply 1123-1124.
73. Williams DJ. The work of Eduard Pernkopf, et al. 37th Annual Meeting of the Association of Medical Illustrators; 1982/10/13, 1982; Anaheim, CA.
74. Williams DJ. The history of Eduard Pernkopf's Topographische Anatomie des Menschen. *J Biocommun.* 1988;15(2):2-12.
75. Hildebrandt S. *The Anatomy of Murder: Ethical Transgressions and Anatomical Science during the Third Reich.* New York: Berghahn Books; 2016.
76. Hayek H. *Die menschliche Lunge.* Berlin: Springer-Verlag; 1953.
77. Stieve H. *Der Einfluss des Nervensystems auf Bau und Tätigkeit der Geschlechtsorgane des Menschen.* Stuttgart: Thieme; 1952.
78. Voss H, Herrlinger R. *Taschenbuch der Anatomie.* Jena: Gustav-Fischer-Verlag; 1946.
79. Israel HA, Seidelman WE. Nazi origins of an anatomy text: the Pernkopf atlas. *JAMA.* 1996;276(20):1633; author reply 1634.
80. Israel HA, Seidelman WE. Origins of the Pernkopf anatomy atlas: In reply. *JAMA.* 1997;277:1123.
81. Ernst E. A leading medical school seriously damaged: Vienna 1938. *Ann Intern Med.* 1995;122(10):789-792.
82. Muehlberger K. Enthebungen an der medizinischen. Fakultät 1938–1945. *Wien Klin Wochenschr.* 1998b;110:115-120.
83. Ebenbauer A, Schuetz W. Origins of the Pernkopf anatomy atlas: In reply. *JAMA.* 1997;277:1123-1124.
84. Akademischer Senat der Universität Wien. Senatsprojekt der Universität Wien: Untersuchungen zur Anatomischen Wissenschaft in Wien 1938–1945. (Unpublished Manuscript). In: Akademischer Senat der Universität Wien.; 1998.
85. Carstens PA. Revisiting the Infamous Pernkopf Anatomy Atlas: Historical Lessons for Medical Law and Ethics. *Fundamina.* 2012;18(2):23-49.

86. Hildebrandt S. How the Pernkopf controversy facilitated a historical and ethical analysis of the anatomical sciences in Austria and Germany: a recommendation for the continued use of the Pernkopf atlas. *Clin Anat*. 2006;19(2):91-100.
87. Atlas MC. Ethics and access to teaching materials in the medical library. *Med Law*. 2000;19(3):463-473.
88. Atlas MC. Ethics and access to teaching materials in the medical library: the case of the Pernkopf atlas. *Bull Med Libr Assoc*. 2001;89(1):51-58.
89. Angell M. The Nazi hypothermia experiments and unethical research today. *N Engl J Med*. 1990;322(20):1462-1464.
90. Berger RL. Nazi science--the Dachau hypothermia experiments. *N Engl J Med*. 1990;322(20):1435-1440.
91. Schmaltz F. Otto Bickenbach's Human Experiments with Chemical Warfare Agents at the Concentration Camp Natzweiler in the Context of the SS-Ahnenerbe and the Reichsforschungsrat. In: Eckart WU, ed. *Man, Medicine and the State. The Human Body as an Object of Government Sponsored Research in the 20th Century.*: Franz Steiner Verlag; 2006:139-156.
92. Rogers EM. *Diffusion of Innovations*. 5th ed. New York, NY: Simon and Schuster; 2003.
93. Macri DM, Tagliaventi MR, Bertolotti F. A grounded theory for resistance to change in a small organization. *Journal of Organizational Change Management*. 2002;15(3):292-310.
94. Andreatta B. *Wired to Resist: The Brain Science of Why Change Fails and a New Model for Driving Success*. Santa Barbara, CA: 7th Mind Publishing; 2017.
95. Scott JW. Scott's parabola. *BMJ*. 2001;323:1477.
96. Hull L, Athanasiou T, Russ S. Implementation Science: A Neglected Opportunity to Accelerate Improvements in the Safety and Quality of Surgical Care. *Ann Surg*. 2017;265(6):1104-1112.
97. Dearing JW. Evolution of diffusion and dissemination theory. *J Public Health Manag Pract*. 2008;14(2):99-108.
98. Milat AJ, Li B. Narrative review of frameworks for translating research evidence into policy and practice. *Public Health Res Pract*. 2017;27(1).
99. Graham ID, Logan J, Harrison MB, et al. Lost in knowledge translation: time for a map? *J Contin Educ Health Prof*. 2006;26(1):13-24.
100. Field B, Booth A, Iltot I, Gerrish K. Using the Knowledge to Action Framework in practice: a citation analysis and systematic review. *Implement Sci*. 2014;9:172.
101. Brownson RC, Fielding JE, Maylahn CM. Evidence-based public health: a fundamental concept for public health practice. *Annu Rev Public Health*. 2009;30:175-201.
102. Peters DH, Adam T, Alonge O, Agyepong IA, Tran N. Implementation research: what it is and how to do it. *BMJ*. 2013;347:f6753.
103. Theobald S, Brandes N, Gyapong M, et al. Implementation research: new imperatives and opportunities in global health. *Lancet*. 2018;392(10160):2214-2228.
104. Colquhoun H, Leeman J, Michie S, et al. Towards a common terminology: a simplified framework of interventions to promote and integrate evidence into health practices, systems, and policies. *Implement Sci*. 2014;9:51.
105. Brownson RC, Colditz GA, Proctor EK. *Dissemination and Implementation research in Health: Translating Science to Practice*. New York, NY: Oxford University Press; 2018.
106. Proctor E, Silmere H, Raghavan R, et al. Outcomes for implementation research: conceptual distinctions, measurement challenges, and research agenda. *Adm Policy Ment Health*. 2011;38(2):65-76.
107. Damschroder LJ, Aron DC, Keith RE, Kirsh SR, Alexander JA, Lowery JC. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. *Implement Sci*. 2009;4:50.
108. Glasgow RE, Vogt TM, Boles SM. Evaluating the public health impact of health promotion interventions: the RE-AIM framework. *Am J Public Health*. 1999;89(9):1322-1327.
109. Glasgow RE, Lichtenstein E, Marcus AC. Why don't we see more translation of health promotion research to practice? Rethinking the efficacy-to-effectiveness transition. *Am J Public Health*. 2003;93(8):1261-1267.
110. Dziewaltowski DA, Glasgow RE, Klesges LM, Estabrooks PA, Brock E. RE-AIM: evidence-based standards and a Web resource to improve translation of research into practice. *Ann Behav Med*. 2004;28(2):75-80.
111. Glasgow RE, Vinson C, Chambers D, Khoury MJ, Kaplan RM, Hunter C. National Institutes of Health approaches to dissemination and implementation science: current and future directions. *Am J Public Health*. 2012;102(7):1274-1281.

112. Zerhouni E. Medicine. The NIH Roadmap. *Science*. 2003;302(5642):63-72.
113. Westfall JM, Mold J, Fagnan L. Practice-based research--"Blue Highways" on the NIH roadmap. *JAMA*. 2007;297(4):403-406.
114. Khoury MJ, Gwinn M, Ioannidis JP. The emergence of translational epidemiology: from scientific discovery to population health impact. *Am J Epidemiol*. 2010;172(5):517-524.
115. Callard F, Rose D, Wykes T. Close to the bench as well as at the bedside: involving service users in all phases of translational research. *Health Expect*. 2012;15(4):389-400.
116. Ericsson KA. Deliberate practice and acquisition of expert performance: a general overview. *Acad Emerg Med*. 2008;15(11):988-994.
117. JH. B. *Mastery Learning: Theory and Practice*. New York, NY: Holt, Rinehart, and Winston; 1971.
118. Ericsson KA, Krampe RT, Tesch-Romer C. The role of deliberate practice in the acquisition of expert performance. *Psychol Rev*. 1993;100:363-406.
119. Ericsson KA, Lehmann AC. Expert and exceptional performance: Evidence of maximal adaptation to task constraints. *Annu Rev Psychol*. 1996;47:273-306.
120. de Groot AD. *Thought and Choice in Chess*. 2nd English ed. The Hague, The Netherlands: Mouton Publishers; 1978.
121. Ericsson KA, Charness N, Feltovich PJ, R. HR. *The Cambridge Handbook of Expertise and Expert Performance*. New York, NY: Cambridge University Press; 2006.
122. Vickers AJ, Bianco FJ, Serio AM, et al. The surgical learning curve for prostate cancer control after radical prostatectomy. *J Natl Cancer Inst*. 2007;99(15):1171-1177.
123. Tracey TJ, Wampold BE, Lichtenberg JW, Goodyear RK. Expertise in psychotherapy: an elusive goal? *Am Psychol*. 2014;69(3):218-229.
124. Waljee JF, Curtin C. Quality assessment in hand surgery. *Hand Clin*. 2014;30(3):329-334, vi.
125. Ericsson KA. Acquisition and maintenance of medical expertise: a perspective from the expert-performance approach with deliberate practice. *Acad Med*. 2015;90(11):1471-1486.
126. Alderson D. Developing expertise in surgery. *Med Teach*. 2010;32(10):830-836.
127. Moulton CA, Regehr G, Lingard L, Merritt C, MacRae H. Slowing down to stay out of trouble in the operating room: remaining attentive in automaticity. *Acad Med*. 2010;85(10):1571-1577.
128. Anderson JR. Acquisition of cognitive skill. *Psychol Rev*. 1982;89:360-406.
129. Fitts PM, Posner MI. *Human Performance*. Belmont, CA: Brooks/Cole; 1967.
130. Djulbegovic B, Hozo I, Beckstead J, Tsalatsanis A, Pauker SG. Dual processing model of medical decision-making. *BMC Med Inform Decis Mak*. 2012;12:94.
131. Kahneman D. *Thinking, fast and slow*. New York, NY: Farrar, Straus and Giroux; 2011.
132. Wiegmann DA, ElBardissi AW, Dearani JA, Daly RC, Sundt TM, 3rd. Disruptions in surgical flow and their relationship to surgical errors: an exploratory investigation. *Surgery*. 2007;142(5):658-665.
133. Way LW, Stewart L, Gantert W, et al. Causes and prevention of laparoscopic bile duct injuries: analysis of 252 cases from a human factors and cognitive psychology perspective. *Ann Surg*. 2003;237(4):460-469.
134. Page G, Bordage G, Allen T. Developing key-feature problems and examinations to assess clinical decision-making skills. *Acad Med*. 1995;70(3):194-201.
135. Kotsis SV, Chung KC. Application of the "see one, do one, teach one" concept in surgical training. *Plast Reconstr Surg*. 2013;131(5):1194-1201.
136. Nguyen L, Brunicaudi FC, Dibardino DJ, et al. Education of the modern surgical resident: novel approaches to learning in the era of the 80-hour workweek. *World J Surg*. 2006;30(6):1120-1127.
137. Halstead WS. The training of the surgeon. *John Hopkins Hosp Bull*. 1904;15:267-275.
138. Moore MJ, Bennett CL. The learning curve for laparoscopic cholecystectomy. The Southern Surgeons Club. *Am J Surg*. 1995;170(1):55-59.
139. Bhatti NI, Cummings CW. Competency in surgical residency training: defining and raising the bar. *Acad Med*. 2007;82(6):569-573.
140. Sachdeva AK, Flynn TC, Brigham TP, et al. Interventions to address challenges associated with the transition from residency training to independent surgical practice. *Surgery*. 2014;155(5):867-882.
141. Curran VR, Fleet LJ, Kirby F. A comparative evaluation of the effect of Internet-based CME delivery format on satisfaction, knowledge and confidence. *BMC Med Educ*. 2010;10:10.
142. *Institute of Medicine - Committee on Planning a Continuing Health Care Professional Education Institute. Redesigning continuing education in the health professions*. National Academic Press; 2009.

- mies Press; 2010.
143. Davis DA. How to help professionals maintain and improve their knowledge and skills: Triangulating best practices in medicine. In: Ericsson KA, ed. *The Development of Professional Expertise: Toward Measurement of Expert Performance and Design of Optimal Learning Environments*. New York, NY: Cambridge University Press; 2009:180-202.
 144. Brydges R, Dubrowski A, Regehr G. A new concept of unsupervised learning: directed self-guided learning in the health professions. *Acad Med*. 2010;85(10 Suppl):S49-55.
 145. Teirstein PS, Topol EJ. The role of maintenance of certification programs in governance and professionalism. *JAMA*. 2015;313(18):1809-1810.
 146. Ericsson KA. Necessity is the mother of invention: video recording firsthand perspectives of critical medical procedures to make simulated training more effective. *Acad Med*. 2014;89(1):17-20.
 147. El Ahmadi TY, Harrop J, Batjer HH, Resnick DK, Bendok BR. Blinded peer assessment of surgical skill is feasible and can predict complication rates: a step toward measuring surgical quality. *Neurosurgery*. 2014;74(6):N12-14.
 148. Hashimoto DA, Rosman G, Witkowski ER, et al. Computer Vision Analysis of Intraoperative Video: Automated Recognition of Operative Steps in Laparoscopic Sleeve Gastrectomy. *Ann Surg*. 2019;270(3):414-421.
 149. Goldenberg MG, Jung J, Grantcharov TP. Using Data to Enhance Performance and Improve Quality and Safety in Surgery. *JAMA Surg*. 2017;152(10):972-973.
 150. Jung JJ, Juni P, Lebovic G, Grantcharov T. First-year Analysis of the Operating Room Black Box Study. *Ann Surg*. 2018.
 151. Zevin B, Bonrath EM, Aggarwal R, et al. Development, feasibility, validity, and reliability of a scale for objective assessment of operative performance in laparoscopic gastric bypass surgery. *J Am Coll Surg*. 2013;216(5):955-965 e958; quiz 1029-1031, 1033.
 152. Hu YY, Peyre SE, Arriaga AF, et al. Postgame analysis: using video-based coaching for continuous professional development. *J Am Coll Surg*. 2012;214(1):115-124.
 153. Cope AC, Mavroveli S, Bezemer J, Hanna GB, Kneebone R. Making meaning from sensory cues: a qualitative investigation of postgraduate learning in the operating room. *Acad Med*. 2015;90(8):1125-1131.
 154. Roberts NK, Brenner MJ, Williams RG, Kim MJ, Dunnington GL. Capturing the teachable moment: a grounded theory study of verbal teaching interactions in the operating room. *Surgery*. 2012;151(5):643-650.
 155. Birkmeyer JD, Finks JF, O'Reilly A, et al. Surgical skill and complication rates after bariatric surgery. *N Engl J Med*. 2013;369(15):1434-1442.
 156. Buckley CE, Kavanagh DO, Traynor O, Neary PC. Is the skillset obtained in surgical simulation transferable to the operating theatre? *Am J Surg*. 2014;207(1):146-157.
 157. Crochet P, Aggarwal R, Dubb SS, et al. Deliberate practice on a virtual reality laparoscopic simulator enhances the quality of surgical technical skills. *Ann Surg*. 2011;253(6):1216-1222.
 158. Hu YY, Mazer LM, Yule SJ, et al. Complementing Operating Room Teaching With Video-Based Coaching. *JAMA Surg*. 2017;152(4):318-325.
 159. Greenberg CC, Ghousseini HN, Pavuluri Quamme SR, et al. A Statewide Surgical Coaching Program Provides Opportunity for Continuous Professional Development. *Ann Surg*. 2018;267(5):868-873.
 160. Greenberg CC, Dombrowski J, Dimick JB. Video-Based Surgical Coaching: An Emerging Approach to Performance Improvement. *JAMA Surg*. 2016;151(3):282-283.
 161. Greenberg CC, Ghousseini HN, Pavuluri Quamme SR, Beasley HL, Wiegmann DA. Surgical coaching for individual performance improvement. *Ann Surg*. 2015;261(1):32-34.
 162. Greenberg CC, Klingensmith ME. The Continuum of Coaching: Opportunities for Surgical Improvement at All Levels. *Ann Surg*. 2015;262(2):217-219.
 163. van Gog T, Rummel N. Example-based learning: Integrating cognitive and social-cognitive research perspectives. *Educational Psychology Review*. 2010;22(2):155-174.
 164. Sweller J, Sweller S. Natural information processing systems. *Evolutionary Psychology*. 2006;4(1):434-458.
 165. Bligh J. Problem-based learning in medicine: an introduction. *Postgrad Med J*. 1995;71(836):323-326.
 166. Atkinson RK, Derry SJ, Renkl A, Wortham D. Learning from examples: Instructional principles from the worked examples research. *Review of Educational Research*. 2000;70(2):181-214.
 167. Sweller J, Van Merriënboer JGG, Paas FGWC. Cognitive architecture and instructional design.

- Educational Psychology Review*. 1998;10(3):251-296.
168. Reed SK, Willis D, Guarino J. Selecting examples for solving word problems. *J Educ Psychol*. 1994;86(3):380.
 169. Anderson JR, Fincham JM. Acquisition of procedural skills from examples. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1994;20(6):1322.
 170. Anderson JR, Fincham JM, Douglass S. The role of examples and rules in the acquisition of a cognitive skill. *Journal of Experimental Psychology: Learning, Memory, and Cognition*. 1997;23(4):932.
 171. Cooper G, Sweller J. Effects of schema acquisition and rule automation on mathematical problem-solving transfer. *J Educ Psychol*. 1987;79(4):347.
 172. Paas FG. Training strategies for attaining transfer of problem-solving skill in statistics: A cognitive-load approach. *J Educ Psychol*. 1992;84(4):429. *ogy Section A*. 1999;52(4):957-979.
 179. Rizzolatti G, Craighero L. The mirror-neuron system. *Annu Rev Neurosci*. 2004;27:169-192.
 180. Tettamanti M, Buccino G, Saccuman MC, et al. Listening to action-related sentences activates fronto-parietal motor circuits. *J Cogn Neurosci*. 2005;17(2):273-281.
 181. Grezes J, Decety J. Functional anatomy of execution, mental simulation, observation, and verb generation of actions: a meta-analysis. *Hum Brain Mapp*. 2001;12(1):1-19.
 182. Hurley S. The shared circuits model (SCM): how control, mirroring, and simulation can enable imitation, deliberation, and mindreading. *Behav Brain Sci*. 2008;31(1):1-22; discussion 22-58.
 183. Kalyuga S. Expertise reversal effect and its implications for learner-tailored instruction. *Educational Psychology Review*. 2007;19(4):509-539.
 184. Sweller J, Ayres PL, Kalyuga S, Chandler P. The expertise reversal effect. *Educational Psychologist*. 2003;38(1):23-31.
 185. Bandura A. *Social foundations of thought and action: A social cognitive theory*. Englewood Cliffs, NJ: Prentice Hall; 1986.
 186. Sweller J. Cognitive load during problem solving: effects on learning. *Cong Sci*. 1988;12:257-285.
 187. van Merriënboer JJ, Sweller J. Cognitive load theory in health professional education: design principles and strategies. *Med Educ*. 2010;44(1):85-93.
 188. Sweller J. Instructional implications of David C. Geary's evolutionary educational psychology. *Educ Psychol*. 2008;43(4):214-216.
 189. Tarmizi RA, Sweller J. Guidance during mathematical problem solving. *J Educ Psychol*. 1988;80(4):424.
 190. Mousavi SY, Low R, Sweller J. Reducing cognitive load by mixing auditory and visual presentation modes. *J Educational Psychol*. 1995;87(2):319.
 191. Chandler P, Sweller J. Cognitive load theory and the format of instruction. *Cogn Instr*. 1991;8(4):293-332.
 192. van Merriënboer JJG, Schuurman JG, De Croock MBM, Paas FGWC. Redirecting learners' attention during training: Effects on cognitive load, transfer test performance and training efficiency. *Learning and Instruction*. 2002;12(1):11-37.
 193. Van Gog T, Paas F, Van Merriënboer JJ, G. Effects of studying sequences of process-oriented and product-oriented worked examples on troubleshooting transfer efficiency. *Learn Instr*. 2008;18(3):211-222.
 194. Decker PJ. Effects of different symbolic coding stimuli in behavior modeling training. *Pers Psychol*. 1984;37(4):711-720.
 195. Driskell JE, Copper C, Moran A. Does mental practice enhance performance? *J Appl Psychol*. 1994;79(4):481.
 196. De Koning BB, Tabbers HK, Rikers RMJP, Paas F. Towards a framework for attention cueing in instructional animations: Guidelines for research and design. *Educ Psychol Rev*. 2009;21(2):113-140.
 197. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med*. 2004;79(10 Suppl):S70-81.
 198. Kalyuga S, Sweller J. Measuring knowledge to optimize cognitive load factors during instruction. *J Educ Psychol*. 2004;96(3):558.
 199. Van Gog T, Kester L, Paas F. Effects of worked examples, example-problem, and problem-example pairs on novices' learning. *Contemp Educ Psychol*. 2011;36(3):212-218.
 200. Renkl A, Atkinson RK. Structuring the transition from example study to problem solving in cognitive skill acquisition: A cognitive load perspective. *Educ Psychol*. 2003;38(1):15-22.
 201. Reisslein J, Atkinson RK, Seeling P, Reisslein M. Encountering the expertise reversal effect with

- a computer-based environment on electrical circuit analysis. *Learn Instr.* 2006;16(2):92-103.
202. Ritter EM. Invited Editorial LAP-VEGaS Practice Guidelines for Video-based Education in Surgery: Content is Just the Beginning. *Ann Surg.* 2018. [Published online ahead of print].
 203. Venturini AH. The Earliest-Known Extant Motion Picture of Anesthesia in the World was Filmed in Buenos Aires. *J Anesth Hist.* 2015;1(2):55-57.
 204. Prober CG, Khan S. Medical education reimaged: a call to action. *Acad Med.* 2013;88(10):1407-1410.
 205. Jones-Bonfiglio KD, Willett T, Ng S. An evaluation of flipped e-learning experiences. *Med Teach.* 2018;40(9):953-961.
 206. Bourdain A. *Kitchen Confidential: Adventures in the Culinary Underbelly.* New York, NY: HarperCollins Publishers; 2001.
 207. Rapp AK, Healy MG, Charlton ME, Keith JN, Rosenbaum ME, Kapadia MR. YouTube is the Most Frequently Used Educational Video Source for Surgical Preparation. *J Surg Educ.* 2016;73(6):1072-1076.
 208. Toolabi K, Parsaei R, Elyasinia F, Zamanian A. Reliability and Educational Value of Laparoscopic Sleeve Gastrectomy Surgery Videos on YouTube. *Obes Surg.* 2019;29(9):2806-2813.
 209. Pitcher GS, Newton DH, Amendola MF. Common Femoral Artery Access on YouTube: What Practices are Being Shown and Who is Delivering the Message? *J Surg Educ.* 2017;74(3):455-458.
 210. Sevinc M. Educational value of Internet videos in vascular access. *J Vasc Access.* 2019;20(5):537-544.
 211. Celentano V, Smart N, Cahill RA, et al. Use of laparoscopic videos amongst surgical trainees in the United Kingdom. *Surgeon.* 2018.
 212. Raikos A, Waidyasekara P. How useful is YouTube in learning heart anatomy? *Anat Sci Educ.* 2014;7(1):12-18.
 213. Lemon TI. Concerns about academic publishing on YouTube. *Acad Med.* 2013;88(9):1194.
 214. Samuel N, Alotaibi NM, Lozano AM. YouTube as a Source of Information on Neurosurgery. *World Neurosurg.* 2017;105:394-398.
 215. Ward B, Ward M, Nicheporuck A, Alaeddin I, Paskhover B. Assessment of YouTube as an Informative Resource on Facial Plastic Surgery Procedures. *JAMA Facial Plast Surg.* 2018. [Published online ahead of print].
 216. Sheahan G, Reznick R, Klinger D, Flynn L, Zevin B. Comparison of Personal Video Technology for Teaching and Assessment of Surgical Skills. *J Grad Med Educ.* 2019;11(3):328-331.
 217. Saun TJ, Zuo KJ, Grantcharov TP. Video Technologies for Recording Open Surgery: A Systematic Review. *Surg Innov.* 2019;26(5):599-612.
 218. Vara AD, Wu J, Shin AY, Sobol G, Wiater B. Video Recording With a GoPro in Hand and Upper Extremity Surgery. *J Hand Surg Am.* 2016;41(10):e383-e387.
 219. Celentano V, Smart N, McGrath J, et al. LAP-VEGaS Practice Guidelines for Reporting of Educational Videos in Laparoscopic Surgery: A Joint Trainers and Trainees Consensus Statement. *Ann Surg.* 2018. [Published online ahead of print].
 220. Guo PJ, Kim J, Rubin R. How video production affects student engagement: an empirical study of MOOC videos. *Proceedings of the First Association of Computing Machinery Conference on Learning at Scale.* 2014:41-50.
 221. Lau KHV, Farooque P, Leydon G, Schwartz ML, Sadler RM, Moeller JJ. Using learning analytics to evaluate a video-based lecture series. *Med Teach.* 2018;40(1):91-98.
 222. Kim J, Guo PJ, Seaton DT, Mitros P, Gajos KZ, Miller RC. Understanding in-video dropouts and interaction peaks in online lecture videos. *Proceedings of the first ACM conference on Learning @ scale conference.* 2014:31-40.
 223. Wu S, Rizoiu M-A, Xie L. Beyond Views: Measuring and Predicting Engagement in Online Videos. *arXiv.* 2018:1709.02541.
 224. Dong C, Goh PS. Twelve tips for the effective use of videos in medical education. *Med Teach.* 2015;37(2):140-145.
 225. Rana J, Besche H, Cockrill B. Twelve tips for the production of digital chalk-talk videos. *Med Teach.* 2017;39(6):653-659.
 226. Norman MK. Twelve tips for reducing production time and increasing long-term usability of instructional video. *Med Teach.* 2017;39(8):808-812.
 227. Yavner SD, Pusic MV, Kalet AL, et al. Twelve tips for improving the effectiveness of web-based multimedia instruction for clinical learners. *Med Teach.* 2015;37(3):239-244.
 228. Yue C, Kim J, Ogawa R, Stark E, Kim S. Applying the cognitive theory of multimedia learning:

- an analysis of medical animations. *Med Educ*. 2013;47(4):375-387.
229. Ellaway R. Apples and architraves: a descriptive framework for e-learning research. *Med Teach*. 2010;32(1):95-97.
 230. Topps D, Helmer J, Ellaway R. YouTube as a platform for publishing clinical skills training videos. *Acad Med*. 2013;88(2):192-197.
 231. Zendejas B, Brydges R, Hamstra SJ, Cook DA. State of the evidence on simulation-based training for laparoscopic surgery: a systematic review. *Ann Surg*. 2013;257(4):586-593.
 232. Schendel S, Montgomery K, Sorokin A, Lionetti G. A surgical simulator for planning and performing repair of cleft lips. *J Craniomaxillofac Surg*. 2005;33(4):223-228.
 233. Kantar RS, Plana NM, Diaz-Siso JR, Flores RL. Simulation-Based Cleft Surgery Education: From Theory to Real-Time Application. *Plast Reconstr Surg*. 2019.
 234. Plana NM, Rifkin WJ, Kantar RS, et al. A Prospective, Randomized, Blinded Trial Comparing Digital Simulation to Textbook for Cleft Surgery Education. *Plast Reconstr Surg*. 2019;143(1):202-209.
 235. Durning SJ, Artino AR, Jr., Schuwirth L, van der Vleuten C. Clarifying assumptions to enhance our understanding and assessment of clinical reasoning. *Acad Med*. 2013;88(4):442-448.
 236. Higgs J, Jones M, Loftus S, Christensen N. *Clinical Reasoning in the Health Professions*. 3rd ed. Boston, MA: Elsevier Health Sciences; 2008.
 237. Elstein AS, Shulman LS, Sprafka SA. *Medical Problem Solving: an Analysis of Clinical Reasoning*. Cambridge, MA: Harvard University Press; 1978.
 238. Ericsson KA. An expert-performance perspective of research on medical expertise: the study of clinical performance. *Med Educ*. 2007;41(12):1124-1130.
 239. Bizzocchi J, Schell R. Rich-narrative case study for online PBL in medical education. *Acad Med*. 2009;84(10):1412-1418.
 240. DelSignore LA, Wolbrink TA, Zurakowski D, Burns JP. Test-Enhanced E-Learning Strategies in Postgraduate Medical Education: A Randomized Cohort Study. *J Med Internet Res*. 2016;18(11):e299.
 241. Vaona A, Banzi R, Kwag KH, et al. E-learning for health professionals. *Cochrane Database Syst Rev*. 2018;1:CD011736.
 242. Jacobs ZG, Elnicki DM, Perera S, Weiner DK. An E-learning Module on Chronic Low Back Pain in Older Adults: Effect on Medical Resident Attitudes, Confidence, Knowledge, and Clinical Skills. *Pain Med*. 2018;19(6):1112-1120.
 243. Cheung JJH, Kulasegaram KM, Woods NN, Moulton CA, Ringsted CV, Brydges R. Knowing How and Knowing Why: testing the effect of instruction designed for cognitive integration on procedural skills transfer. *Adv Health Sci Educ Theory Pract*. 2018;23(1):61-74.
 244. Dawe SR, Pena GN, Windsor JA, et al. Systematic review of skills transfer after surgical simulation-based training. *Br J Surg*. 2014;101(9):1063-1076.
 245. Kempton SJ, Bentz ML. Making Master Surgeons Out of Trainees: Part I. Teaching Surgical Judgment. *Plast Reconstr Surg*. 2016;137(5):1646-1653.
 246. Mayer RE. Applying the science of learning: evidence-based principles for the design of multimedia instruction. *Am Psychol*. 2008;63(8):760-769.
 247. Daley BJ, Torre DM. Concept maps in medical education: an analytical literature review. *Med Educ*. 2010;44(5):440-448.
 248. Moulton ST, Turkay S, Kosslyn SM. Does a presentation's medium affect its message? PowerPoint, Prezi, and oral presentations. *PLoS One*. 2017;12(7):e0178774.
 249. Hyll M, Schvarcz R, Manninen K. Exploring how medical students learn with the help of a digital presentation: a qualitative study. *BMC Med Educ*. 2019;19(1):210.

PART I

ESTABLISHING VIDEO-BASED LEARNING IN NERVE SURGERY

CHAPTER 2

VIDEO-BASED LEARNING IN SURGERY

ESTABLISHING SURGEON ENGAGEMENT AND UTILIZATION OF VARIABLE-DURATION VIDEOS

Based on:

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* Joint first authors

ABSTRACT

OBJECTIVE

To measure surgeon engagement and preferred video duration in a video-based learning program for nerve surgery.

BACKGROUND

Educational videos can improve, standardize, and democratize best practices in surgery. To improve care internationally, educators must optimize their videos for learning. However, surgeon engagement and optimal video duration remain undefined.

METHODS

A *YouTube* channel and a video-based learning website, *PASSIO Education* (passioeducation.com), were examined from 2011 to 2017. We assessed views, geographic location, audience engagement (average percent of video watched), audience retention (percent of viewers at each timepoint), and usage of short (median 7.4, range 4.1–20.3 min) and long (median 17.2, range 6.1–47.7 min) video formats for the same procedures. A survey of *PASSIO Education* membership examined preferred video duration.

RESULTS

Our 117 nerve surgery videos attained over 3 million views with 69% originating outside of the United States. While *YouTube* achieved more international exposure, *PASSIO Education* attained a greater mean engagement of 48.4% (14.3% absolute increase, $P < 0.0001$). Surveyed surgeons ($n = 304$) preferred longer videos when preparing for infrequent or difficult cases compared with routine cases ($P < 0.0001$). Engagement declined with video duration, but audience retention between short and long video formats was correlated ($t_b = 0.52$, $P < 0.0001$).

CONCLUSIONS

For effective spread of best practices, we propose the joint use of *YouTube* for audience outreach and a surgeon-focused platform to maximize educational value. Optimal video duration is surgeon- and case-dependent and can be addressed through offering multiple video durations and interactive viewing options.

INTRODUCTION

Video-based learning (VBL) has generated new opportunities to acquire and improve surgical skills.¹⁻⁸ VBL intuitively integrates the traditional method of teaching, summarized by the adage “See one, Do one, Teach one,” as videos can provide excellent operative visualization, instruction, and coaching by expert mentors.⁹⁻¹¹ Consequently, surgeons have embraced online videos for skills acquisition and case preparation.¹²⁻¹⁴ To address international disparities in surgical management and the economic consequences of surgical disease,^{15,16} VBL could provide opportunities to standardize best practices, improve quality of care, reduce complications, and lower operative costs.

Halsted’s apprenticeship model for surgical education is tailored toward producing competent surgeons through graduated responsibility and oversight by physician organizations (e.g. ACGME) during residency and fellowship.^{10,11,17} However, continued professional development is heterogeneous and involves participating in societal conferences, surgical workshops, and maintenance of certification.¹⁸ Anders Ericsson asserts that most surgeons reach an early plateau of average performance that is maintained over the entirety of their careers.¹⁹ By contrast, some surgeons continue to improve and eventually achieve “expert performance” by engaging in “deliberate practice” in a focused area of surgery and with emphasis on education and teaching. Educational videos may facilitate such deliberate practice in surgery because they can be watched several times, slowed down, and analyzed for subtle nuances in technique.^{20,21}

In recent years, surgical videos have experienced rapid and widespread adoption that has at times outpaced quality and safety control.²² Studies examining content on *YouTube*, the most common source for surgical videos,²³ report substantial variability in educational value due to nonuniform production quality, unclear intent (education or marketing), and lack of a peer-review process.²⁴⁻²⁷ In response, the recent LAP-VEGaS consensus statement offers 37 guidelines to standardize and improve the educational quality of videos in laparoscopic surgery.²⁸ A subsequent editorial emphasized the need to optimize videos for learning by managing cognitive load, tailoring content to different levels of expertise, maximizing audience engagement, and limiting video duration.^{29,30} However, a reference for surgeon engagement in operative videos has not been established, and factors influencing preferred video duration have not yet been studied.

In 2011, we launched an online educational resource, *Nerve Surgery* (nervesurgery.wustl.edu), to advance the treatment of peripheral nerve injuries (Fig. 2.1). Surgical videos narrated by a master nerve surgeon were incorporated into *Nerve Surgery* and were later published on *YouTube* to improve audience outreach. As our video library and viewership grew, we sought to enhance the educational value of our videos for surgeons. In 2016, we capitalized on design principles used in massive open online courses, such as *Khan Academy* and *edX.org*,³¹⁻³⁴ and consolidated our *Nerve Surgery* videos into a pilot VBL platform, *PASSIO Education* (passioeducation.com), dedicated to modern surgical education.

FIGURE 2.1. Longitudinal development of the video-based learning program. The development of the VBL program began in 2011 with *Nerve Surgery*, when the videos were also published on *YouTube*. The collective experience gathered was used to develop *PASSIO Education* to integrate the videos into a robust and interactive user experience.^a

The goals of this report are to examine viewing behaviors over our 7-year experience in video education to 1) evaluate an approach for VBL in surgery, 2) provide a benchmark for surgeon engagement, and 3) evaluate preferred video duration and the utility of offering different video durations for the same procedures.

METHODS

STUDY DESIGN

Viewing behaviors were examined for an online surgical education program developed at the Washington University School of Medicine. Our channel on the online video service *YouTube* (youtube.com/nervesurgery) was assessed from its launch on February 3, 2011 to December 31, 2017. Our educational website, *PASSIO Education* (*PASSIO*), was assessed from its launch on April 6, 2016 to December 31, 2017. Institutional Review Board approval was obtained (#201505011).

COMPOSITION OF VIDEO LIBRARY

A total of 117 nerve surgery videos were produced (by A.Y. and S.E.M.): 59 (50%) were available on both *YouTube* and *PASSIO*, 7 (6%) on *YouTube* only, and 51 (44%) on *PASSIO* only. Videos were grouped into 3 categories: 85 surgical (42 unique procedures), 26 lecture, and 6 nonoperative clinical videos. Videos on *PASSIO* were accompanied by written descriptions of deidentified patient information, surgical indications, surgeon disclosures, and operative steps. Viewers could select specific operative steps to view within each video, and they could also select different playback speeds.

We defined surgical videos as point-of-view recordings with voice-overs describing operative steps. They were edited into two formats with different durations: long (median 17.2, range 6.1–47.7 min) and short (median 7.4, range 4.1–20.3 min). Both formats included all operative steps, but the long video was intended to show the

cadence of the procedure and improve surgical flow, while the short video was intended for just-in-time learning.³⁵ Clinical videos were recordings of nonoperative activities such as clinical examinations. Lecture videos were voiced over instructional courses made with *PREZI* (*prezi.com*).

EDUCATIONAL PLATFORM AND ONLINE VIDEO SERVICES

2

Access to all *PASSIO* content was free, and users were asked to complete a 1-time registration to capture demographic information. Because this registration process could impede access, a login was only required to access 40% of videos (clinical, lecture, and long format surgical videos). Registered users, or *PASSIO* members, reported occupation, institution, and surgical specialty if applicable.

Google Analytics (google.com/analytics) was used to assess website traffic on *PASSIO* from 2016 to 2017. Extracted metrics included numbers of users, user sessions, and page visits. Viewing data were extracted from *YouTube* using Creator Studio (youtube.com/analytics) and from *PASSIO*'s video hosting service, *Brightcove*, using Video Cloud (studio.brightcove.com). *YouTube* and *Brightcove* data included daily video views, geographic location of viewers, watch-time, and audience engagement. Watch-time was defined as the average minutes played of each video, irrespective of rewatched or skipped sections. Audience engagement was defined as watch-time divided by video duration. Additionally, *YouTube* provided relative audience retention for each video, or the change in views at each second of a video compared to all *YouTube* videos with similar duration (Fig. 2.2A, B). Because our videos were open-access, they were susceptible to social, or "viral," sharing.^{26,36} These viral videos misrepresent usage by our target surgical audience and, therefore, were excluded from analysis (Fig. 2.3).

ASSESSMENT OF PREFERRED VIDEO DURATION

A survey was distributed to all *PASSIO* members to determine preferred surgical video duration in several clinical situations and to evaluate use of short and long video formats. A total of 1731 emails were sent, which corresponded to 1605 unique *PASSIO* members (76% physicians, 8% did not specify) after removal of inactive or duplicate email addresses. Surgeons indicated their preferred video duration on a scale ranging from 1 (shortest possible, a video trailer under 1 min) to 13 (longest possible, unedited video of a full procedure). Ranges for our short (4 to 6) and long (8 to 10) video formats were provided as references. Users also reported their preferred *PASSIO* video format in various clinical situations.

To examine similarities in how video formats were watched, relative audience retention was assessed for the 16 procedures on *YouTube* with both short and long video formats (Fig. 2.2C).

FIGURE 2.2. Comparison of relative audience retention between short and long video formats. (A) Absolute audience retention is the percent of total viewers who watched each timepoint of a video. The absolute audience retention curves for the short video on ulnar nerve transposition are depicted. Irrespective of total video duration, viewers are most likely to drop off within the first 15 s of every video, partly due to accidental clicks. (B) The relative audience retention curve represents absolute audience retention adjusted by the average audience retention for all YouTube videos of similar length. (C) The black hatch lines indicate matching video frames for each video in the pair. The shaded areas between hatch lines represent the operative steps at which reviewers graded the increases or decreases in relative audience retention. A sample of operative steps for this procedure (ulnar nerve transposition) is noted below the long video retention curve. Overall, grades were correlated within each pair ($tB = 0.52$, $P < 0.0001$).

FIGURE 2.3. Visual identification of viral videos by views. Viral videos may misrepresent usage by a surgical audience. A video was considered to be viral if its daily views plot had a peaked contour (sharp ascent and descent) and if its views during this peak exceeded the sum of all non-viral views on that day. Four videos were identified (carpal tunnel release – short, peroneal nerve ganglion cyst removal – short, combined Guyon’s canal and carpal tunnel release – short, median nerve decompression at the forearm – long), and their daily views were compared to the sum of all non-viral videos.

For comparison within video pairs, each procedure was separated into a series of prespecified operative steps (median 35 steps/procedure), and the independent axis of each relative audience retention curve was converted from time (minutes) to operative steps (count). Changes in relative audience retention between each step were graded on a scale ranging from -5 to +5, with 0 indicating no change in audience retention from the previous step.

STATISTICAL ANALYSIS

Audience engagement was compared between *YouTube* and *PASSIO* using multiple linear regression with video duration as a covariate. Differences in engagement between short and long video formats were assessed by paired sample *t* test. Demographics of surveyed surgeons were compared to registered *PASSIO* physicians by chi-square goodness of fit test. Responses were compared by McNemar or Wilcoxon signed-rank tests, and practicing surgeon responses were compared with trainee responses by Fisher exact or Wilcoxon rank-sum tests. Bonferroni adjustment was used to correct for multiple testing. The relationship between relative audience retention for short and long formats was assessed by the Kendall τ_b correlation coefficient. All statistical analyses were performed using SAS, version 9.4, and *P* values less than 0.05 were considered statistically significant.

RESULTS

INITIAL EFFORTS IN ONLINE EDUCATION: NERVE SURGERY

Nerve Surgery was introduced in 2011 as an open-access online resource for surgeons treating nerve injuries. Three major categories were offered: anatomy and physiology, examination techniques, and surgical options. The website offered over 500 images which included anatomical illustrations, cadaveric dissections, intraoperative photos, and clinical examinations. While surgical videos were incorporated into certain topics on *Nerve Surgery*, they were not the initial focus of our approach in multimedia learning.

Ultimately, 85 videos were available on *Nerve Surgery*, although just 12 were not also available on *YouTube* or *PASSIO*: 3 surgical, 1 lecture, and 8 nonoperative clinical videos. In its first 2 years, *Nerve Surgery* received 67,509 user sessions (39,885 non-bounced user sessions) with an average session duration of 2 minutes. These metrics suggest that much of the user traffic was driven by quick internet searches for keywords and images, rather than purposely visiting and exploring the website. Videos over this period received 15,834 views, with 38% being accessed through *Nerve Surgery* and the remaining directly through the affiliated *Vimeo* video channel. Despite only contributing up to 13% of total user sessions on *Nerve Surgery*, the videos received an overall favorability score of 4.6 out of 5 in a pilot survey of 62 surgeons from the American Society for Peripheral Nerve (ASPN) (presented at the 24th Annual ASPN Meeting, Rowe A.G., et al, January 23–25, 2015). Additionally, we received positive feedback from unsolicited emails that could be categorized as appraisal, dissemination, or implementation (Table 2.1). This refined our efforts in VBL and, as our library grew, we sought to identify a video publishing service that offered improved audience outreach: *YouTube*.⁷

IMPROVING VIDEO OUTREACH AND DIFFUSION: YOUTUBE

YouTube offers educators an immense potential audience and high accessibility due to its integration and preferential ranking with Google Search.³ While facilitating international exposure, these features also encourage viral sharing in the public domain. Additionally, surgeon viewers cannot be distinguished from patients or other non-medical viewers and maximizing engagement for the general audience may actually diminish educational value for surgeons. Therefore, we leveraged our *YouTube* channel's popularity to recruit surgeons to a pilot VBL platform that could more accurately assess their learning behaviors: *PASSIO Education*.

Table 2.1. Comments of support, dissemination, and implementation. Feedback was received via email and was categorized as either support, dissemination, or implementation.

Country of Origin	Comments of Support
United States	Thank you very much for your excellent videos!
United States	Your most recent videos on "super selective" [nerve transfer] is epic. You both did a good job and the sound is crystal clear.
United States	You have been such an inspiration for me over the years. I have watched every video you have published and do appreciate the hard work in producing them.
United States	Your videos are amazingly helpful as your technique articles on [nerve transfers]. Our fellows tell me that they live-and-die by your surgical videos. They're great! Keep 'em coming!
United States	The pearls in the videos are very insightful. For someone like myself who does not do a ton of these procedures, the 20-minute tune up video is a great resource.
United States	I used your videos throughout training and without doubt, I would consider them an invaluable resource. I perform complex nerve surgery and without this resource, I doubt I would feel the same comfort level.
Colombia	Thank you for making all your videos and sharing all your knowledge. You are making my job easier and more effective. I love watching your videos. You have a lovely voice, I'm in love.
Egypt	I'm getting great knowledge and nuances from your marvelous video collection about nerve surgery. Thank you, you are great.
India	[Expert surgeon] does such a wonderful job and the slides are so well organized.
Saudi Arabi	The videos are great and have watched them many times over.
South Korea	I've watched all of your videos and believe you are one of the best in nerve surgery.
Spain	I am a young, enthusiastic surgeon and have been enjoying your online teachings for several years. I believe your work is helping a lot of surgeons worldwide and improving patients outcomes.
Turkey	I am a medical student and want to thank you for such a great and useful website.
Country of Origin	Comments Regarding Dissemination
United States	This platform remains critical for those of us who don't have the privilege to learn from [an expert surgeon] directly.
United States	These videos are a great way to encourage us "old dogs" in private practice to try the latest and greatest. This far, far, far better than seeing a presentation at a meeting, reading an article, and even better than visiting the operating room, where I'd only see it once and probably not as well as the videos.
United States	You have a profound understanding of anatomy, but a better gift of making it easy for others not at your [expert level], to learn.
India	I had difficulty understanding nerve surgeries, but after having watched the videos, it seemed very easy. I passed my super specialty in plastic surgery mainly because of these videos.
India	I am an independent surgeon in a more rural area of India. All the scientific content was extremely useful to me. It was of high-quality and my patients immensely benefited.
Karachi	This was incredible, just incredible. I have no other words to describe it. On one hand, I wanted to stop the video conference because it was nearly midnight in the United States, but on the other hand, the audience was spellbound and they did not want to stop.
Palestine	The exemplary hard work of putting those videos together is making a big difference in places where getting good training is difficult (or, nearly impossible). They are making a difference in many people's lives. Thank you.
Ukraine	We are a team of neurosurgeons from Ukraine, who specializes in nerve surgery, and have been impressed by your contributions. PASSIO Education has a significant influence on our everyday work: it serves us as an invaluable educational resource for reviewing and enhancing our surgical practice, which we continuously refer to. Ukraine is currently in an open armed conflict, which affects the east territories of our country. Therefore, we occasionally deal with acute gunshot nerve traumas and, more frequently, with late consequences of different kinds of peripheral nerve traumas. Our neurosurgical team is relatively new and do not always have the appropriate experience to be able to provide treatment of such complex injuries. We are hoping if there is an opportunity to visit your hospital and a course on practical training to help us develop our own standards of patient care. We would grateful.

Country of Origin	Comments Regarding Implementation
United States	Your video allowed me the confidence to do the [nerve transfer] for a patient who shattered their humerus and transected the [nerve]. All technically went very well.
United States	Your [nerve transfer] videos gave me the courage and confidence to help my patient with an operation I hadn't done before. My patient's deformed, palsied hand is back to full-typing with individual finger and thumb extension.
United States	I appreciate the videos and have incorporated your techniques into my practice with good results.
United States	I released the [nerve] just like your video! Very, very helpful. Almost like learning from [expert surgeon] directly. They are very educational.
United States	I want to share gratitude. I recently performed a [nerve decompression]. Prior to the surgery, I watched your video and the actual surgery could not have gone any smoother. Your pearls of wisdom about the anatomy and the surgical procedure were incredibly helpful. My patient greatly benefitted from your excellent work.
United States	Your video series on [nerve decompression] has bailed me out of many cases. I have safely performed over 10 nerve surgeries in my first 2 months of practice due to you. The books are good, your videos are great.
United States	Thank you for the [nerve transfer] videos. Just did one and it went well.
United States	I have been an ardent follower of your educational videos since the beginning. I've seen all of them and read your book. I've developed an interest in nerve surgery after seeing many war patients with nerve entrapments due to traumatic injuries. Most of these patients were told to live with their pain. After seeing how simple a [nerve decompression] can change these patients' lives, I've started to develop a clinical ability to recognize more complex presentations. I've found your videos on a [provocative test] and it definitely works! I travel to several countries to see these patients and they are grateful.
United States	You've changed the way I think concerning the behavior of nerve injuries. I thought you might change my practice, but now I'm sure you did. The preliminary results made me very thankful and appreciative of your efforts. I used to consider patients having [extremity pain], as not serious patients, and only time may help them recover. Now, I consider nerve exploration and [nerve transfers] for the QUALITY of recovering nerves. My juniors are using your [examination classification]. We could not thank you enough.
United States	I want to express my gratitude for your excellent work and videos detailing your diagnostic and surgical techniques. Your technique videos for [neuroma management] allowed me to make an outstanding difference in patients' quality of life. One patient had a complex history of failed surgeries and was debilitated for years with chronic pain. Your [neuroma management] technique was performed remarkably, and this patient was extremely happy with their success, [pain free], and is able to exercise and enjoy their activities. I showed this patient your videos and this patient was able to exactly identify with your patients. I believe having seen that had us both fully invested in the treatment and the patient is grateful for the care close to home.
Cameroon	Your website and videos are really indispensable. I mean, really, really top notch. I couldn't undertake surgery without the videos and narration. We are really grateful for all of the [principal authors'] work. It is helping people in Africa, and I'm sure for others from around the world.
Canada	The videos are amazing. They helped me perform a [nerve transfer].
Canada	I performed a [nerve transfer] as seen in your video and it was EXACTLY as you described. You are doing great things in education. I was at a [surgical subspecialty] course in the United States, and the instructor asked to turn the camera away, so that we wouldn't see a key part of the procedure. Your videos reveal everything about technique.
Greece	Thank you for your extraordinary educative video of a [nerve decompression], where you describe step-by-step the whole procedure. I was able to perform the operation myself after watching it several times without difficulty, although it was my first one. It felt like it was my 100th time.
Sweden	Thank you for your instructive videos. I'm late in my career as a surgeon and still love my practice in [specialty]. I remember specifically, when I looked at your [nerve decompression] video: I watched it six times on my way to the operating room. It was and is so easy to follow your instructions. I really love them.
United Kingdom	I had to do a [nerve decompression] last week and the video was just fantastic. It made what I always found to be a difficult procedure into something that was so controlled and thorough.
United Kingdom	You have no idea how much of an influence you had on my practice in such a short time - you totally changed my mindset on how to approach patients crippled by nerve pain and yet are "too hot to touch" for other physicians.

Our *YouTube* channel received 3.2 million views from its 66 nerve surgery videos. However, four viral *YouTube* videos accounted for 2.6 million views. Surgeons likely contributed to a minority of these viewers,^{26,36} since nerve surgery is a small subspecialty shared by plastic and reconstructive surgery, orthopedic surgery, and neurosurgery. Following exclusion of viral videos, the remaining 62 videos accounted for 561,292 views. Seventy percent of these were from outside the United States, which is similar to the global outreach achieved by a separate *YouTube* channel intended for global medical education.³

2

DEVELOPING A VIDEO PLATFORM: PASSIO EDUCATION

PASSIO was available for 20 months, and 1144 users registered during this time. Eighty-one percent were physicians (38% identified as attending surgeons, 33% as trainees, and the remaining did not specify level of training), 6% were medical students, and 3% were patients. Over this period, *PASSIO* had 28,232 user sessions (average session duration of 4 min), and its videos received 16,761 views. While these views are modest compared to *YouTube*, *PASSIO*'s growth matched the first 20 months of our *YouTube* channel (Fig. 2.4). There were also substantial similarities in international viewership between *YouTube* and *PASSIO* (Table 2.2). A notable distinction is that China was ranked 7th on *PASSIO* despite scarce *YouTube* viewership.

FIGURE 2.4. Comparison of daily sessions/views for the first 20 months of *Nerve Surgery*, *YouTube*, and *PASSIO*. User sessions over the first 20 months of *Nerve Surgery* and *PASSIO* were similar. Our *YouTube* channel was launched on February 3, 2011, and *PASSIO* was launched on April 6, 2016. The 2 platforms experienced similar growth in viewership over their first 20 months. *PASSIO* may have benefitted from the popularity of our *YouTube* platform.

FIGURE 2.5. Audience engagement of educational videos. (A) Videos on both *YouTube* and *PASSIO* demonstrated a logarithmic decline in audience engagement with increased video duration, similar to findings from (*) a report by Kim et al³⁰ of video dropout rate (%) for 862 videos on edX.org. Red circles represent individual *YouTube* videos and blue circles represent individual *PASSIO* videos; regression lines are fit for each collection of videos. The greater variability in *PASSIO* engagement at each video duration may be explained by lower views for each video compared to *YouTube*. *PASSIO* achieved higher engagement compared to *YouTube* (14.3% absolute increase, 95% CI 11.5% to 17.0%, $P < 0.0001$). (B) Surgical videos engagement and (C) lecture videos engagement were also reported separately.

TABLE 2.2. Geographic distribution of video views for YouTube and PASSIO.

Rank	YouTube		PASSIO	
	Country	Views (pct. Total)	Country	Views (pct. Total)
1	United States	30.2	United States	43.9
2	India	7.2	Spain	5.0
3	United Kingdom	4.8	United Kingdom	4.9
4	Canada	3.4	Canada	4.4
5	Turkey	2.9	India	3.3
6	Egypt	2.7	Egypt	2.5
7	Brazil	2.7	China	2.0
8	Mexico	2.6	Australia	1.9
9	South Korea	2.3	Brazil	1.7
10	Germany	2.0	South Korea	1.4

With a confirmed surgeon-predominant userbase, a benchmark for video engagement could be established as a reference for surgeon educators.³⁷ PASSIO videos achieved a mean engagement of 48.4%, and short format videos had 8.4% higher engagement than long videos (absolute increase, 95% CI 5.5%–11.3%, $P < 0.0001$). In comparison, mean engagement for our YouTube collection was 34.3%, which is consistent with a study of over 5 million popular YouTube videos.³⁷ Similar to PASSIO, short format videos had 13.0% higher engagement than long format videos (absolute increase, 95% CI 11.0%–15.0%, $P < 0.0001$). For both collections, a logarithmic decline in engagement was observed with increasing video duration (Fig. 2.5), which has been reported in other YouTube channels and massive open online courses.^{33,37} After controlling for duration, videos on PASSIO achieved higher overall engagement than YouTube (14.3% absolute increase, 95% CI 11.5%–17.0%, $P < 0.0001$). Comparison of the subset of videos that were available on both PASSIO and YouTube over the same time period yielded similar results (16.1% absolute increase, 95% CI 13.2%–19.0%, $P < 0.0001$).

Analytics provide insight on how learners interact with websites and access materials, allowing educators to optimize users' online experience. An advantage of developing a custom VBL platform is the ability to combine user and viewing analytics to generate insights into surgeon learning behaviors. For example, PASSIO required user logins to access 46 videos with 3,023 total views, indicating that registered users watched an average of 3 login-protected videos each. These videos accounted for 38% of PASSIO's collection, but only 18% of total views. In comparison, the same video categories comprised 36% of videos and 31% of total views on YouTube, as well as 51% of videos and 50% of total views on *Nerve Surgery*. Given the total number of views and non-bounced user sessions, these views occurred over 5-6 sessions. Furthermore, up to 43% of revolving registered users engaged PASSIO monthly, an upper limit estimation made by dividing non-bounced user sessions and total registered users.

The overall survey response rate was 20% (320/1605). Following exclusion of medical students (5%), patients (2%), and other non-physicians (9%), the surgeon response rate was 23% (304/1342). Country of origin was available for all surveyed surgeons and for 93% of registered *PASSIO* physicians. The majority of responses (68%) originated from 53 countries outside the United States. The 10 countries with the most *PASSIO* views (Table 2.2) contributed 68% of *PASSIO* surgeons and 61% of surgeon responses; response rates from these countries were not significantly different from their membership proportions ($P = 0.12$). While 40% of registered *PASSIO* physicians were trainees (residents and fellows), they comprised just 23% of survey responses ($P < 0.0001$). Non-trainees were in practice for a median of 10 years (range 1–44 yrs).

Most surgeons (72%) endorsed using *PASSIO* at least once per month. Eighty-eight percent watched the long videos and preferred this format when learning new techniques, preparing for difficult or infrequent cases, improving patient outcomes, and teaching surgical trainees or medical students (Fig. 2.6). Surgeons were more likely to use the short format when they had limited preparation time or when preparing for routine cases compared with infrequent or difficult cases ($P < 0.0001$). Similarly, on our 13-point scale, respondents demonstrated a preference for longer videos when preparing for new (median 9) or infrequent cases (median 10) compared with routine cases (median 6) ($P < 0.0001$). There were no significant differences between practicing surgeon and trainee responses.

Half of surgeons (52%) used the operative steps listed alongside each video to navigate through procedures and to skip to areas of interest. This viewing behavior was also apparent in the relative audience retention curves, which demonstrated peaks of high interest and troughs of low interest (Fig. 2.2C). Comparison of relative audience retention within video pairs demonstrated moderate correlation ($t_b = 0.52$, $P < 0.0001$), indicating that, despite an overall decline in engagement with increased duration, viewers watched the 2 video formats in a similar manner.

FIGURE 2.6. Preferred video duration in multiple practice situations. *PASSIO* surgeons were asked to indicate their preferred video format for each of the situations shown. The “Both Videos” option indicates that the surgeon typically watched both short and long video formats. On average, surgeons preferred the short format when they had limited time for case preparation and when browsing a topic.

DISCUSSION

As VBL becomes increasingly prominent in surgical training,^{38,39} it is imperative that educators improve the accessibility and educational value of these resources. From our 7-year experience in VBL for nerve surgery, we demonstrate that widespread distribution of engaging videos can be achieved through the joint use of *YouTube* and a custom VBL website. In this model, *YouTube* funnels surgeons to a surgeon-focused website, which can track viewing behaviors. Analyzing these behaviors can guide content creation to improve surgeon engagement, which promotes acquisition of clinical judgement and operative skills.

Surgeon engagement, and its relationship to video duration, established by our program may serve as a benchmark for surgeon educators. Notably, *PASSIO* videos demonstrated higher engagement than *YouTube* videos despite substantial overlap between the 2 collections. Possible explanations are that 1) surgeons had higher motivation to watch instructional videos than the general *YouTube* audience, 2) *PASSIO* members were more confident of each video's quality and educational value, and 3) the operative steps listed next to each video allowed viewers to skip or rewatch areas of interest, which may have helped to ease cognitive load.^{29,40,41}

To maximize engagement in online courses, it has been suggested that video duration be limited to 10 minutes.^{29,30} However, this recommendation had not been evaluated for surgical videos, which must often summarize procedures lasting several hours. While our long video format demonstrated lower engagement than the short format, *PASSIO* members indicated a need for longer videos when learning new techniques, managing infrequent or difficult cases, and improving patient outcomes. Long videos can reveal subtle operative details, such as moments to “slow down” or areas of expected frustration, that may be essential for reducing cognitive burden, decreasing stress, and improving the success of cases.⁴² The lower engagement in long videos despite surgeons' stated preferences has several possible explanations. Surgeons may watch a single long video over multiple viewing sessions, which would result in a low average watch-time despite having watched the entire video. Surgeons may also revisit a long video multiple times to rewatch only a few operative steps. Additionally, surgeons watching the long format whose needs would be better met by the short format (e.g., for a routine case) may be more likely to exit out of the video than in the opposite situation.

Analysis of relative audience retention indicated that, despite differences in engagement, viewers watched both video formats in similar ways. Just as real case duration depends on surgeon expertise and case difficulty, optimal video duration is dependent on the interplay between multiple factors (Fig. 2.7). Short videos may be appropriate for conference proceedings, summarizing technique, or just-in-time learning before a case. However, for safe and effective implementation of surgical techniques across different experience levels and clinical situations, we recommend offering variable video durations.

FIGURE 2.7. Factors influencing optimal video duration. Optimal video duration depends on surgeon factors, procedure factors, and the video's intended purpose.

STANDARDIZATION OF BEST PRACTICES AND INTERNATIONAL IMPACT

The purpose of an international educational program is not to recruit patients or referrals to master surgeons, but rather to improve the quality and availability of healthcare globally (Fig. 2.8). Online educational programs have the ability to transcend geographic, economic, racial, sex, and language barriers to improve surgical training worldwide. Conversely, they facilitate sharing of expertise by a diverse group of surgeons. A partnership between educators and master surgeons in these programs may, with appropriate instructional design, facilitate the translation of evidence-based techniques to widespread clinical practice.⁴³ Additionally, self-directed learning through surgical videos may facilitate deliberate practice to help elevate practicing surgeons to expert performers (Fig. 1.5).^{20,21} While surgical videos can be powerful marketing tools, a focus on self-promotion and patient referrals may impede global progress within a field.

Viewing data from educational programs may also help generate future global health investigations and target healthcare interventions. For example, relatively high interest in procedures for brachial plexus injury in some countries may indicate a need to reduce injuries or to improve local training on that topic. Furthermore, in countries such as China, a custom VBL website may circumvent restrictions on popular video services like *YouTube* to better understand the demand for specific surgical topics in those countries.

FUTURE RESEARCH APPLICATIONS IN VIDEO-BASED LEARNING

Three recent systematic reviews have examined the value of online education, or e-Learning, in orthopedics, otolaryngology, and surgery in general.^{44–46} Each concluded that e-Learning has potential to improve knowledge, clinical performance, and/or learners' satisfaction with teaching materials. However, the effects of video

education in planned interventions do not necessarily translate to self-directed usage patterns, and real-world viewing behaviors must be understood to ensure knowledge translation in actual practice. Although videos on *PASSIO* demonstrated higher engagement than on *YouTube*, on average, surgeons still watched less than half of each video during a viewing session. The implementation of surgical practices through educational videos relies on both video quality (e.g., content and filming practices) and surgeon engagement.

To optimize audience attention, educators should research and employ evidence-based principles for video design.³¹ For example, we demonstrate a role for both short and long video formats, but it remains unclear how to best edit multi-hour surgical procedures into shorter videos. Future studies may explore strategies for differential filming or editing. Additionally, videos may be offered in multiple languages or with translated subtitles to promote usage by non-English speakers.

There is also a need to establish generalizability of this model to other surgical specialties. In addition to methods of video distribution, the expertise and motivations of video authors must also be considered. In our experience, authors should be opinion leaders,⁴⁷ or established experts with the ability to influence attitudes and behaviors in their focused clinical areas, who have experience practicing in a surgical teaching environment. They should also be interested, above else, in sharing their knowledge in sufficient detail to facilitate implementation of best practices. As a proof of concept, an additional 12 videos were produced with 4 master surgeons (J.E.J., R.M.Z., G.A.P., L.M.B.), who are considered opinion leaders in their fields and renowned educators. These videos performed similarly to the 117 nerve surgery videos (Table 2.3), and they can be found on our new multispecialty VBL platform, Learn Surgery (learnsurgery.wustl.edu). We encourage surgeon educators to evaluate our VBL model in their own online educational programs and to report their analytics data.

TABLE 2.3 Total number of videos and video performance by surgical specialty.

Surgical Specialty	Surgeon	Total Videos	Video Date Range	Total Views	Median Engagement
Nerve Surgery	S. E. M.	117	2/3/2011 – 12/31/2017	3,191,955	41%
Pediatric Microsurgery	R. M. Z.	4	6/27/2014 – 12/31/2017	22,222	23%
Foot and Ankle Surgery	J. E. J.	4	9/22/2014 – 12/31/2017	33,083	36%
Cardiothoracic Surgery	G. A. P.	2	2/13/2016 – 12/31/2017	3,951	26%
Minimal Invasive Surgery	L. M. B.	2	9/26/2017 – 12/31/2017	1,246	30%

LIMITATIONS

Analytics algorithms were not publicly available and therefore could not be appraised for their consistency or reliability. Google Analytics also does not record time spent on the last page of a session, meaning that reported session duration is an underestimate. Nonetheless, average session duration is a common website metric that can be used to compare websites. Analytics tools provided by *YouTube* and *Brightcove* reported different metrics that prevented some comparisons between video services. For example, information on relative audience retention was not available on *PASSIO*, which precluded assessment of surgeon retention. Our *PASSIO* survey response rate of 20% is similar to what has been reported in recent physician surveys.^{48–50}

CONCLUSION

This novel study establishes a benchmark for surgeon engagement and evaluates preferred surgical video duration. It also introduces a framework for VBL programs that utilizes *YouTube* to channel surgeons to a modern VBL platform for guiding instructional design. Similar VBL programs may be created in other surgical specialties to equitably share best practices and improve quality of care.

FIGURE 2.8. Geographic distribution of views on YouTube. Visualization of the international exposure of our educational program in nerve surgery with 66% originating outside the United States. India, Egypt, Turkey, and South Korea contributed a larger share of views than expected from general YouTube geographic trends. While YouTube was restricted in China, we achieved substantial views from China through PASSIO.

REFERENCES

1. Hu YY, Mazer LM, Yule SJ, et al. Complementing operating room teaching with video-based coaching. *JAMA Surg.* 2017;152:318–325.
2. Rapp AK, Healy MG, Charlton ME, et al. YouTube is the most frequently used educational video source for surgical preparation. *J Surg Educ.* 2016;73: 1072–1076.
3. Tackett S, Slinn K, Marshall T, et al. Medical education videos for the world: an analysis of viewing patterns for a YouTube channel. *Acad Med.* 2018;8:1150–1156
4. Yang K, Perez M, Hubert N, et al. Effectiveness of an integrated video recording and replaying system in robotic surgical training. *Ann Surg.* 2017;265:521–526.
5. Hashimoto DA, Bynum WE, Lillemoe KD, et al. See more, do more, teach more: surgical resident autonomy and the transition to independent practice. *Acad Med.* 2016;91:757–760.
6. Langerman A, Grantcharov TP. Are we ready for our close-up?: Why and how we must embrace video in the OR. *Ann Surg.* 2017;266:934–936.
7. Topps D, Helmer J, Ellaway R. YouTube as a platform for publishing clinical skills training videos. *Acad Med.* 2013;88:192–197.
8. Jyot A, Baloul MS, Finnesgard EJ, et al. Surgery website as a 24/7 adjunct to a surgical curriculum. *J Surg Educ.* 2018;75:811–819.
9. Birkmeyer JD, Finks JF, O'Reilly A, et al. Surgical skill and complication rates after bariatric surgery. *N Engl J Med.* 2013;369:1434–1442.
10. Kerr B, O'Leary JP. The training of the surgeon: Dr. Halsted's greatest legacy. *Am Surg.* 1999;65:1101–1102.
11. Kotsis SV, Chung KC. Application of the "see one, do one, teach one" concept in surgical training. *Plast Reconstr Surg.* 2013;131:1194–1201.
12. Ahmet A, Gamze K, Rustem M, et al. Is video-based education an effective method in surgical education? A systematic review. *J Surg Educ.* 2018;3: 1150–1158.
13. Beyer-Berjot L, Palter V, Grantcharov T, et al. Advanced training in laparoscopic abdominal surgery: a systematic review. *Surgery.* 2014;156:676–688.
14. Schmidt RS, Shi LL, Sethna A. Use of streaming media (YouTube) as an educational tool for surgeons: a survey of AAFPRS members. *JAMA Facial Plast Surg.* 2016;18:230–231.
15. Alkire BC, Shrime MG, Dare AJ, et al. Global economic consequences of selected surgical diseases: a modelling study. *Lancet Glob Health.* 2015;3 suppl 2:S21–27.
16. Burwell SM. Setting value-based payment goals—HHS efforts to improve U.S. health care. *N Engl J Med.* 2015;372:897–899.
17. Coleman JJ, Esposito TJ, Rozycki GS, et al. Early subspecialization and perceived competence in surgical training: are residents ready? *J Am Coll Surg.* 2013;216:764–771.
18. Berkowitz LR. The American Board of Internal Medicine Maintenance of Certification Program: cocreating the Future. *JAMA Surg.* 2015;150:699–700.
19. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med.* 2004;79(10 suppl):S70–81.
20. Ericsson KA. Necessity is the mother of invention: video recording firsthand perspectives of critical medical procedures to make simulated training more effective. *Acad Med.* 2014;89:17–20.
21. Ericsson KA. Acquisition and maintenance of medical expertise: a perspective from the expert-performance approach with deliberate practice. *Acad Med.* 2015;90:1471–1486.
22. Deal SB, Alseidi AA. Concerns of quality and safety in public domain surgical education videos: an assessment of the critical view of safety in frequently used laparoscopic cholecystectomy videos. *J Am Coll Surg.* 2017;225: 725–730.
23. Rodriguez HA, Young MT, Jackson HT, et al. Viewer discretion advised: is YouTube a friend or foe in surgical education? *Surg Endosc.* 2018;32:1724–1728.
24. Pitcher GS, Newton DH, Amendola MF. Common femoral artery access on YouTube: what practices are being shown and who is delivering the message? *J Surg Educ.* 2017;74:455–458.
25. Samuel N, Alotaibi NM, Lozano AM. YouTube as a source of information on neurosurgery. *World Neurosurg.* 2017;105:394–398.
26. Lemon TI. Concerns about academic publishing on YouTube. *Acad Med.* 2013;88:1194.
27. Ward B, Ward M, Nicheporuck A, et al. Assessment of YouTube as an informative resource on facial plastic surgery procedures. *JAMA Facial Plast Surg.* 2018 [Epub ahead of print].
28. Celentano V, Smart N, McGrath J, et al. LAP-VEGaS practice guidelines for reporting of edu-

- cational videos in laparoscopic surgery: a joint trainers and trainees consensus statement. *Ann Surg.* 2018;268. 920–926.
29. Ritter EM. Invited editorial LAP-VEGaS practice guidelines for video-based education in surgery: content is just the beginning. *Ann Surg.* 2018;268. 927–929.
30. Guo PJ, Kim J, Rubin R. How video production affects student engagement: an empirical study of MOOC videos. *Proceedings of the First Association of Computing Machinery Conference on Learning at Scale.* 2014;41–50.
31. Mayer RE. Applying the science of learning: evidence-based principles for the design of multimedia instruction. *Am Psychol.* 2008;63:760.
32. Mor Y, Ferguson R, Wasson B. Learning design, teacher inquiry into student learning and learning analytics: a call for action. *Br J Educ Technol.* 2015;46:221–229.
33. Kim J, Guo PJ, Seaton DT, et al. Understanding in-video dropouts and interaction peaks in online lecture videos. *Proceedings of the first ACM conference on Learning scale conference.* 2014;31–40.
34. Polsani PR. Use and abuse of reusable learning objects. *J Digit Inform.* 2003;3.
35. Prince MJ, Felder RM. Inductive teaching and learning methods: definitions, comparisons, and research bases. *J Eng Educ.* 2006;95:123–138.
36. Broxton T, Interian Y, Vaver J, et al. Catching a viral video. *J Intell Inform Syst.* 2013;40:241–259.
37. Wu S, Rizoju M-A, Xie L. Beyond views: measuring and predicting engagement in online videos. *arXiv.* 2018;1709.02541.
38. Wittich CM, Agrawal A, Wang AT, et al. Flipped classrooms in graduate medical education: a national survey of residency program directors. *Acad Med.* 2018;93:471–477.
39. Grosser J, Bientzle M, Shiozawa T, et al. Acquiring clinical knowledge from an online video platform: a randomized controlled experiment on the relevance of integrating anatomical information and clinical practice. *Anat Sci Educ.* 2018 [Epub ahead of print].
40. Sewell JL, Boscardin CK, Young JQ, et al. Learner, patient, and supervisor features are associated with different types of cognitive load during procedural skills training: implications for teaching and instructional design. *Acad Med.* 2017;92:1622–1631.
41. Van Merriënboer JJ, Ayres P. Research on cognitive load theory and its design implication for E-learning. *Educ Technol Res Dev.* 2005;53:5–13.
42. Moulton CA, Regehr G, Lingard L, et al. Slowing down to stay out of trouble in the operating room: remaining attentive in automaticity. *Acad Med.* 2010;85:1571–1577.
43. Colditz GA, Brownson R, Proctor E. The promise and challenges of dissemination and implementation research. *Dissemination and Implementation Research in Health: Translating Science to Practice.* 2012;3–22.
44. Jayakumar N, Brunckhorst O, Dasgupta P, et al. e-Learning in surgical education: a systematic review. *J Surg Educ.* 2015;72:1145–1157.
45. Tarpada SP, Hsueh WD, Gibber MJ. Resident and student education in otolaryngology: a 10-year update on e-learning. *Laryngoscope.* 2017;127:E219–E224.
46. Tarpada SP, Morris MT, Burton DA. E-learning in orthopedic surgery training: a systematic review. *J Orthop.* 2016;13:425–430.
47. Brownson RC, Colditz GA, Proctor EK. *Dissemination and Implementation Research in Health: Translating Science to Practice.* Oxford: Oxford University Press; 2017.
48. Epstein S, Tran BN, Capone AC, et al. The current state of surgical ergonomics education in US surgical training: a survey study. *Ann Surg.* 2018.
49. Hasak JM, Novak CB, Patterson JMM, et al. Prevalence of needlestick injuries, attitude changes, and prevention practices over 12 years in an urban academic hospital surgery department. *Ann Surg.* 2018;267:291–296.
50. Scully RE, Davids JS, Melnitchouk N. Impact of procedural specialty on maternity leave and career satisfaction among female physicians. *Ann Surg.* 2017;266:210–217.

CHAPTER 3

THE ROLE OF SURGICAL VIDEO ON RESIDENT PERFORMANCE OF CARPAL TUNNEL RELEASE

A CADAVERIC SIMULATION-BASED, PROSPECTIVE,
RANDOMIZED, BLINDED STUDY

Based on:

Yee A,* Padovano WM,* Rowe AG, Hill EJR, Fox IK, Moore AM, Coert JH, Mackinnon SE. The Role of Surgical Video on Resident Performance of Carpal Tunnel Release: A Cadaveric Simulation-Based, Prospective, Randomized, Blinded Pilot Study. *Plast Reconstr Surg.* 2020;145(6):1455-1463.

* Joint first authors

ABSTRACT

OBJECTIVE

To evaluate the impact of an educational surgical video on resident performance of an open carpal tunnel release through an Objective Structured Assessment of Technical Skills (OSATS) and serial questionnaires.

BACKGROUND

Surgical videos are increasingly common in the preparation for operative cases, although their role in residency curricula remains unclear.

METHODS

Twenty-two residents representing six postgraduate years were randomized to receive text-based materials with or without a surgical video before performing a carpal tunnel release on human cadavers. Procedures were video recorded, anonymized, and independently evaluated by three hand surgeons using the OSATS global rating scale, a procedure-specific technical rating scale, a record of operative errors, and pass/fail designation. Residents completed questionnaires before and after the procedure to track confidence in their technical skills.

RESULTS

Residents in their first and second postgraduate years ($n=10$) who watched the surgical video committed fewer operative errors (median 4 vs 1.3, $p = 0.043$) and were more confident in their abilities following the procedure (median 75 vs 32, $p = 0.043$) than those receiving text resources alone. There were no significant differences in OSATS performance or questionnaire responses among more senior residents ($n=12$). The technical rating scale was internally consistent (Cronbach α 0.95, 95% CI 0.91 to 0.98), reliable (ICC 0.73, 95% CI 0.40 to 0.88), and correlated with surgical experience (Spearman ρ 0.57, $p = 0.006$).

CONCLUSIONS

Watching an educational surgical video to prepare for a cadaveric procedure significantly reduced operative errors and improved confidence among junior trainees performing a carpal tunnel release.

INTRODUCTION

Surgical training traditionally follows an apprenticeship model, where residents gain expertise through large case volumes and structured mentorship.^{1,2} However, resident work-hour restrictions, increased scrutiny for medical errors, and progressive sub-specialization at teaching centers have made it challenging to attain the skills needed for independent practice through case volume alone.³⁻⁷ Simulations offer trainees a safe and uniform environment to supplement patient experiences,⁸⁻¹⁴ and standardized measures of performance, such as the Objective Structured Assessment of Technical Skills (OSATS),¹⁵⁻¹⁸ have been developed to monitor skill acquisition and provide reliable feedback.^{19,20} Unfortunately, simulations for many procedures, such as those in nerve or microvascular surgery,²¹ require animal or cadaveric models that have high costs and limited availability.^{22,23}

Video-based learning has become a prominent educational tool for practicing surgeons.²⁴⁻²⁷ Videos may promote self-directed learning, improve accessibility of educational content, and reduce educational costs.^{28,29} Educational videos offer several potential benefits for surgical residents. They can reinforce techniques and reasoning learned in the operating room, and they may also augment operative experiences by allowing learners to pause, slow down, or replay specific parts of procedures.³⁰⁻³² Once produced, videos can serve as reusable resources for self-directed and self-paced learning.^{28,33} With appropriate distribution, they may transcend geographic, socioeconomic, institutional, and language barriers to allow trainees to learn best practices, clinical and intraoperative reasoning, and new operative approaches from expert surgeons worldwide.²⁷ Such knowledge translation is particularly essential to the field of plastic surgery, which consists of many subspecialties and demands creativity, problem-solving, innovation, and ethical practice.^{34,35}

While surgical videos are becoming increasingly popular among trainees, evidence quantifying their effect on resident performance remains sparse. Recent systematic reviews suggest that surgical videos may improve knowledge and learner satisfaction among medical students and residents, but few studies have evaluated whether they can specifically improve technical skills.³⁶⁻³⁹ Further, it remains unclear if videos can improve surgical performance in procedures other than those routinely performed via a visual monitor, such as laparoscopy or arthroscopy. In this randomized study, we examine the role of a surgical video demonstrating an open carpal tunnel release on resident performance in an OSATS and their confidence.

METHODS

STUDY DESIGN

Participants were recruited from all postgraduate years (PGY) of plastic and reconstructive surgery residency and the first two years of general surgery residency programs at Washington University School of Medicine. Residents who had undergone additional postgraduate years of training were excluded. Participation was voluntary, and residents did not receive compensation of any form. Participants were randomly assigned to one of two educational interventions (text resources with or without a surgical video) in a 1:1 ratio using a computer-generated sequence. Residents in each intervention group were not required to use any of the provided resources. Technical skills were then evaluated through an OSATS using a human cadaver model (Fig 3.1). The study design and rationale received institutional review board approval (#201505011). All analyses were intent-to-treat.

FIGURE 3.1. Experimental study design. Residents completed several questionnaires during their assessments and performed a simulated excision of a skin lesion and a carpal tunnel release. Videos of their operative performance were reviewed by a panel of surgeons using OSATS.

PRE-INTERVENTION ASSESSMENT

A questionnaire was administered to establish demographics, training year, approach to case preparation, and self-reported baseline confidence in technical skills using a 100-point visual analogue scale. All residents are required to log the number of procedures performed during their residency, indexed by Current Procedure Terminology (CPT) code. Counts of CPT code 64721 (neuroplasty and/or transposition; median nerve at carpal tunnel) were retrieved for each resident as an objective measure of carpal tunnel release experience. To evaluate baseline technical skills, residents were instructed to excise a simulated 2-cm skin lesion with 1-cm margins on a pigskin model. Each performance was videotaped using a high-definition camcorder, which was held behind the participant by an experienced videographer using a shoulder-mounted rig. The camcorder was positioned such that each performance was recorded over the participant's shoulder to simulate their point-of-view. Videos were edited to remove identifying characteristics and audio. A blinded pan-

el of three attending, board-certified plastic surgeons with subspecialty certification in hand surgery (I.K.F., A.M.M., S.E.M.) independently assessed each baseline video performance using an OSATS global rating scale with 7 subcategories (respect of tissue, time and motion, instrument handling, knowledge of instruments, use of assistants, flow of operation, and knowledge of specific procedure).⁴⁰

EDUCATIONAL INTERVENTION

Residents were required to spend 40 minutes for case preparation prior to performing an open carpal tunnel release without closure on a draped fresh cadaveric arm. They were provided an operative text describing the procedure,⁴¹ an anatomy atlas,⁴² and note-taking materials. The video group was additionally provided an edited, 9-minute intraoperative recording of a carpal tunnel release with a voiced-over description of the operative steps.⁴³ The operative text and video contained similar information as both were developed by the same senior author (S.E.M.), who is an established expert in the management of compressive neuropathies. The operative text and video described the sequence of operative steps for carpal tunnel release in similar detail.

3

POST-INTERVENTION ASSESSMENT

Residents were allowed a maximum of 40 minutes to complete a simulated open carpal tunnel release. They were provided with an instrument tray and a surgical assistant for passive retraction. Operative performances were videotaped and edited in the same fashion as the baseline assessment. The same panel of attending surgeons evaluated each performance using the OSATS global rating scale, a technical rating scale for carpal tunnel release modified from an operative checklist,¹⁷ a tally of operative errors, and pass/fail designation. Residents passed if at least two graders assigned a passing designation. The technical rating scale was comprised of 7 categories derived from the educational materials and established best practices. These included: (1) quality of skin incision, (2) protection of palmar cutaneous branch, (3) identification of the juncture between the thenar and hypothenar fascia, (4) visualization of the transverse carpal ligament, (5) visualization of compressive antebrachial fascia, (6) incision location on the transverse carpal ligament, and (7) completeness of the release. Graders evaluated each category of the global and technical rating scales with a 5-cm visual analogue scale from 1 (minimum score) to 5 (maximum score); overall scores were calculated from the average of subcategory scores. Operative errors were defined a priori by the attendings surgeons and were classified into 6 categories: (1) incision, (2) visualization/exposure, (3) incomplete release, (4) instrument use, (5) tissue damage (e.g. transection of the palmar cutaneous branch of the median nerve), and (6) operating room efficiency. After the simulated cadaveric procedure, residents again reported their confidence in technical skills. They also indicated the strengths and weaknesses of the learning materials (text and video) through open-response feedback (Table 3.1).

TABLE 3.1 Open-response feedback on learning materials.

Feedback	Responses*	
	Text	Video and Text
Strengths of Text		
Provided in-depth background and context	1	3
Provided step-by-step instructions	5	2
Simplifies information	2	3
Highlights key points	3	3
Figures to review at own pace	2	4
Strengths of Video		
Provides good visualization of anatomic steps	-	7
Better conveys technique and operative steps	-	5
Reduces cognitive load	-	2
Weaknesses of Text		
Difficulty visualizing anatomy	6	8
Difficulty knowing if steps were performed correctly	3	0
Does not provide time needed to complete each step	1	0
Difficulty conveying technique	1	3
Increased cognitive effort to link text to figures	0	1
Weaknesses of Video		
Would like more detail	-	5
Makes the procedure look easier than reality	-	1
Navigation through steps not controlled by learner	-	1
Does not provide written step-by-step summary	-	1
Does not describe pre-operative or post-operative care	-	1

* All answers were open-response. Responses were categorized into several feedback statements. Values represent the number of residents who endorsed each statement in their answers. A single resident could endorse multiple statements.

STATISTICAL ANALYSIS

The performance measures were evaluated for their internal consistency, inter-rater reliability, and discriminant validity. To assess internal consistency of the global and technical rating scales, Cronbach α coefficients were calculated using average grades for each subcategory. Inter-rater reliabilities were assessed by intraclass correlation coefficients (ICCs), which were calculated using a two-way random effects model for absolute agreement.⁴⁴ For discriminant validity, the association between CPT count and performance measures were assessed by Spearman rank coefficients or Wilcoxon rank sum test, as appropriate.

Differences in baseline characteristics between intervention groups were assessed by Wilcoxon rank sum test. To assess the impact of the educational intervention,

global and technical scores, number of operative errors, pass/fail designation, and confidence levels (baseline, pre-procedure, post-procedure) were compared between intervention groups by Wilcoxon rank sum test or Fisher exact test. Changes in confidence level within each intervention group were also assessed by Wilcoxon signed rank test. *P*-values were adjusted by false discovery rate (FDR) adjustment to correct for multiple comparisons. Additionally, residents were stratified into two categories, PGY1-2 and PGY3-6, for subgroup analyses to examine how carpal tunnel release experience influenced effects of the educational intervention. These strata were selected because plastic surgery residents at our center have limited hand surgery experience during PGY1-2, but they are on plastic surgery services full-time during subsequent years. CPT counts were compared between strata to evaluate this grouping. All comparisons in this study were two-tailed, and *p*-values less than 0.05 were considered statistically significant. All analyses were performed using SAS, version 9.4 (SAS Institute Inc., Cary, NC).

RESULTS

DEMOGRAPHICS

Of the 22 residents who participated in this study (18 plastic surgery, and 4 general surgery PGY1-2), 12 received the surgical video for case preparation. There were no significant differences in baseline characteristics or strategies for case preparation between intervention groups (Table 3.2). As expected from our residency curriculum, PGY1-2 residents had significantly lower CPT counts for carpal tunnel release than more senior training years (median 0 vs 28, *p* = 0.0001) (Fig 3.2). Among these 10 junior trainees, 6 residents (4 plastic surgery, 2 general surgery) received the surgical video; there was no significant difference in CPT counts between intervention groups (median 0 vs 0, *p* = 0.73).

FIGURE 3.2. Prior carpal tunnel release experience. Boxplots for Current Procedural Terminology (CPT) Code 64721 count for each postgraduate year. For each boxplot, the horizontal line represents median, asterisk represents mean, whiskers extend to furthest data point within 1.5 times the interquartile range, and the lower and upper edges represent the first and third quartile, respectively. Postgraduate years (PGY) 1 and 2 are colored in blue, PGY 3 to 6 are colored in red.

TABLE 3.2. Demographics, confidence, and baseline technical skills of participants.

Characteristic	Education Intervention	
	Text (n=10)	Video and Text (n=12)
Age (year)		
Median (Interquartile)	30.5 (29 – 32)	29.5 (28 - 31.5)
Female Gender (n)	4	5
Postgraduate Year (n)		
PGY1	2	3
PGY2	2	3
PGY3	2	1
PGY4	1	2
PGY5	2	2
PGY6	1	1
CPT Count (n)		
Median (Interquartile)	17 (0 - 26)	5 (0 - 29.5)
Usage of Resources* – (percent of cases)		
Lectures		
Median (Interquartile)	8 (5 - 30)	14 (0 - 25)
Journal Articles		
Median (Interquartile)	50 (25 - 60)	45 (10.5 - 62.5)
Surgical Textbooks/Anatomy Atlas		
Median (Interquartile)	77.5 (50 - 90)	77.5 (50 - 99.5)
Online Resources		
Median (Interquartile)	62 (39 - 99)	88.5 (73 - 100)
Surgical Videos		
Median (Interquartile)	56 (30 - 75)	73 (52.5 - 86.5)
Perceived Adequacy of Resources (100-point scale)		
Median (Interquartile)	72 (55 - 100)	77.5 (58 - 100)
Confidence in Technical Skills (100-point scale)		
Median (Interquartile)	65.5 (50 - 75)	65 (19 - 78)
Baseline Global Rating Scale (score)		
Median (Interquartile)	3.39 (2.91 - 3.96)	3.38 (2.95 - 3.49)
* Typical use of resources for case preparation.		

RELIABILITY AND VALIDITY

Cronbach α coefficients for the global and technical rating scales demonstrated excellent internal consistency (Table 3.3). Inter-rater reliabilities of the performance measures were also within previously reported ranges for standardized assessments of residents performance (Table 3.3).^{17,18,45} Furthermore, the performance measures varied as expected with carpal tunnel release experience; higher CPT count was associated with higher global score ($\rho = 0.61$, $p = 0.002$), technical score ($\rho = 0.57$, $p = 0.006$), and pass rate (median 0 vs 24, $p = 0.002$), as well as fewer operative errors ($\rho = 0.53$, $p = 0.01$).

TABLE 3.3. Reliability and validity of performance measures.

Test	Assessments			
	Global Rating Scale	Technical Rating Scale	Operative Errors	Pass/Fail
Reliability				
Cronbach α	0.97	0.95	-	-
Intraclass Correlation Coefficient*	0.89	0.73	0.78	0.84
Validity				
Spearman Rank Coefficient	0.61 ($p=0.002$)	0.57 ($p=0.006$)	0.53 ($p=0.011$)	-
Mann-Whitney U	-	-	-	$p=0.002$

* ICC values are associated with the following 95% confidence intervals: global rating scale 0.73 to 0.95, technical rating scale: 0.40 to 0.88, operative errors 0.55 to 0.90, pass/fail designation 0.67 to 0.93.

IMPACT OF SURGICAL VIDEO

There were no significant differences in performance measures between the non-stratified intervention groups. Nonetheless, the video group was more confident in their surgical skills after watching the video (median +25.5, adjusted $p = 0.073$) than at baseline. Their confidence also remained higher than baseline after the OSATS (median +19, adjusted $p = 0.073$). In comparison, the text-only group did not experience any significant changes in confidence.

To evaluate if effects of the surgical video depended on baseline carpal tunnel release experience, differences in OSATS performance and confidence were examined for residents in PGY1-2 and residents in PGY3-6. For the junior residents ($n=10$), the video group made significantly fewer operative errors than the text-only group (median 4 vs 1.3, adjusted $p = 0.043$) (Table 3.4). Furthermore, a majority of the text-only group committed at least one error in every error category (Table 3.5), while only "incision" and "incomplete release" error categories contained a majority of the video group. Residents in the video group also had higher global scores, technical scores, and pass rate than their peers, although the differences did not achieve statistical significance (Table 3.4). Additionally, when compared to the text-only group, residents in the video group were significantly more confident in

their surgical skills after the OSATS (median 75 vs 32, adjusted $p = 0.043$).

PGY3-6 residents ($n=12$) scored highly on performance measures regardless of educational group, and no significant differences were identified between the groups (Table 3.4). Nonetheless, irrespective of training year, residents in the video group preferred watching the video to reading text resources during the study period (Table 3.6).

TABLE 3.4. OSATS performance of participants.

Assessment	PGY 1-2 (n=10)			PGY 3-6 (n=12)		
	Text (n=4)	Video and Text (n=6)	P-value	Text (n=6)	Video and Text (n=6)	P-value
Global Rating Scale (score)			0.10			1.00
Median	1.78	2.81		3.71	3.90	
Interquartile	1.58 - 2.44	2.36 - 3.69		3.37 - 4.00	3.76 - 4.25	
Technical Rating Scale (score)			0.10			1.00
Median	2.32	2.88		3.76	3.87	
Interquartile	2.10 - 2.52	2.51 - 4.04		3.49 - 3.96	3.42 - 4.40	
Error Events (count)			0.043*			1.00
Median	4.00	1.33		0.67	0.83	
Interquartile	4.00 - 4.67	0.33 - 2.33		0.33 - 1.33	0 - 1.00	
Pre-OSATS Confidence (100-point scale)			0.46			1.00
Median	35	50.5		87.5	94	
Interquartile	25 - 60	45 - 67		79 - 90	90 - 98	
Post-OSATS Confidence (100-point scale)			0.043*			1.00
Median	32	75		90	87	
Interquartile	23 - 41.5	70 - 80		78 - 100	75 - 100	
Pass Rate (percent)	0	33	0.47	100	100	1.00

* Statistically significant difference after false discovery rate (FDR) adjustment to correct for multiple statistical comparisons.

TABLE 3.5. Number of participants performing at least one operative error for each category.

Error Type	PGY 1-2 (n=10)		PGY 3-6 (n=12)	
	Text (n=4)	Video and Text (n=6)	Text (n=6)	Video and Text (n=6)
Incision	3	4	3	1
Visualization and Exposure	3	2	1	1
Incomplete Release	3	4	1	1
Instrument Use	4	2	2	1
Tissue Damage	3	2	4	4
Operating Room Efficiency	3	2	1	0

TABLE 3.6. Usage of provided learning materials during study period.

Characteristic	PGY 1-2 (n=10)		PGY 3-6 (n=12)	
	Text (n=4)	Video and Text (n=6)	Text (n=6)	Video and Text (n=6)
Text Usage (views)*				
Median	4	1	2	1
Range	2-5	1-3	1-3	0-2
Video Usage (views)*				
Median	-	3	-	2
Range	-	2-5	-	1-3

*Values represent the number of times residents referenced the text resources or video during the study period.

DISCUSSION

In this randomized study, residents in their first and second postgraduate years who watched a surgical video made fewer operative errors than those who used text-based resources alone. These residents were also significantly more confident in their skills after the OSATS than their counterparts, which has multiple possible explanations. Junior residents in the video group may have actually performed better than their peers during the OSATS despite non-significant differences in global and technical rating scores. Indeed, the video group did score higher in all performance measures, although sample sizes in our subgroup analyses could not reliably detect true differences between intervention groups. The post-hoc power was 0.44 for global score in the PGY1-2 subgroup, and more than twice as many participants would have been required to achieve at least 80% power at a 95% confidence level. Based on these findings, future studies will likely require multiple training programs or take place over multiple years to achieve such a large sample size.

As has been demonstrated in multiple recent studies,³⁶⁻³⁸ residents in the video group may have had a more positive learning experience than the text-only group, and this may have positively influenced their self-image. It is possible that resident confidence acted as a surrogate for learner satisfaction, or how prepared residents felt for the OSATS. Alternatively, watching the surgical video may have led to over-confidence in skills, as has been described in non-surgical instructional videos.⁴⁶ Regardless, the continued improvement in resident confidence after the OSATS in the video group, but not in the text-only group, suggests differences in how junior residents internalized their OSATS performance.

In contrast, senior residents performed well on the OSATS regardless of the educational intervention, and prior studies have also demonstrated that less experienced residents tend to receive the most benefit from videos and simulations.^{21,47,48} However, standardized performance measures may not be able to detect subtle differences in technique, and the educational resources may not have been optimized for experienced trainees. Furthermore, surgical videos may provide junior trainees with an initial mental model,⁴⁹ that senior trainees have already developed through surgical experiences. According to this theory, understanding any complex system requires a mental model, or an understanding of the system's structural components and their behaviors.^{50,51} For a surgical procedure, the structural components represent surgical anatomy and component behaviors describe how a surgeon's actions deform, expose, or alter anatomic structures. As a surgeon gains experience with a procedure, their mental model is constantly refined to reflect a more comprehensive understanding of anatomic variations, scarring, strain on tissues, and areas to "slow down."⁵²

High-definition, point-of-view surgical videos may provide junior trainees with an initial mental model by allowing them to visualize a procedure's structural components and behaviors.^{51,53} However, senior trainees, who have already constructed a detailed mental model, may require more advanced videos that emphasize nuances in technique. Given the need to improve performance at all training levels,^{4,6} we recommend that future studies on this topic offer separate educational resources to junior and senior residents to accommodate differences in baseline expertise.

As educators and surgical societies spend an ever-growing amount time, resources, and effort to develop videos for resident education, there is a need to understand how surgeons learn and to improve the educational value of surgical videos.^{26,27} Future research should, for example, examine strategies for optimizing cognitive load, improving attention and information retention, and adapting video content to differences in surgeon expertise.^{26,28} Additionally, to evaluate the real-world effectiveness of surgical videos, there is a need to examine how videos are utilized for self-directed learning by both trainees and practicing surgeons. Our group is currently exploring how surgeons watch videos in our online educational program to incorporate thoughtful instructional design,²⁷ and we encourage other online educators to study the viewing habits of their learners.

LIMITATIONS

Substantial resources were required to provide an OSATS for each resident, including the time to evaluate each performance. This limited the number of participants who could be enrolled in this study. Similar to previous studies on e-learning in surgery,³⁶ our small sample size reduced our power to detect more subtle differences in resident performance. Having demonstrated acceptable agreement between evaluators, future studies may reduce costs by evaluating performances with a single evaluator or by crowdsourcing to non-expert evaluators.⁵⁴⁻⁵⁶ Furthermore, the technical rating scale was adapted from a previously validated checklist for the carpal tunnel release with the goal of detecting more subtle differences in technical performance for each item. Although this scale demonstrated acceptable internal validity, additional studies are needed to establish its external validity.

The carpal tunnel release was selected for the OSATS because its relatively low procedural complexity could accommodate a junior training level, although the anatomic area has several structures that may be damaged even by experienced surgeons.⁵⁷ However, the operation may have been too difficult for junior trainees and too easy for senior trainees to demonstrate the full benefits of surgical videos for case preparation: PGY3-6 residents had a 100% pass rate while nearly all PGY1-2 residents failed. Additionally, the educational video may not have been optimized for the specific needs of less experienced trainees. For example, a majority of junior residents in the video group made errors involving the initial incision, and the video could have devoted more time to demonstrating this important step. A recent study demonstrated that an online animation was superior to text for teaching preoperative markings for cleft lip repair to medical students.⁵⁸ This incision animation was later incorporated into a more robust simulation, which combined other animations with intraoperative videos, to effectively teach unilateral cleft lip repair to residents.⁵⁹ Similarly, junior performance in our study may have improved from additional learning modules describing incision placement and relevant anatomical structures, as noted by 42% of trainees "wanting more detail" in their description of a weakness in the surgical video.

CONCLUSION

This novel study establishes the ability of a surgical video to reduce operative errors and improve confidence among plastic surgery residents. It also demonstrates that junior trainees experience the largest gains in performance, suggesting that surgical videos should be introduced early in residency curricula. Furthermore, this study highlights barriers to studying skills acquisition in nerve surgery that may help guide future educational studies and incorporate thoughtful instructional design to enhance the learning experience.

REFERENCES

1. Barnes RW, Lang NP, Whiteside MF. Halstedian technique revisited. Innovations in teaching surgical skills. *Annals of Surgery*. 1989;210(1):118.
2. Carter BN. The fruition of Halsted's concept of surgical training. *Surgery*. 1952;32(3):518-527.
3. Bell Jr RH, Biester TW, Tabuenca A, et al. Operative experience of residents in US general surgery programs: a gap between expectation and experience. *Annals of surgery*. 2009;249(5):719-724.
4. Coleman JJ, Esposito TJ, Rozycki GS, Feliciano DV. Early subspecialization and perceived competence in surgical training: are residents ready? *Journal of the American College of Surgeons*. 2013;216(4):764-771.
5. Hallam M-J, Lo S, Mabvuure N, Nduka C. Implications of rationing and the European Working Time Directive on aesthetic breast surgery: a study of trainee exposure in 2005 and 2011. *Journal of Plastic, Reconstructive & Aesthetic Surgery*. 2013;66(2):e37-e42.
6. Sachdeva AK, Flynn TC, Brigham TP, et al. Interventions to address challenges associated with the transition from residency training to independent surgical practice. *Surgery*. 2014;155(5):867-882.
7. Watson DR, Flesher TD, Ruiz O, Chung JS. Impact of the 80-hour workweek on surgical case exposure within a general surgery residency program. *Journal of surgical education*. 2010;67(5):283-289.
8. Aggarwal R, Grantcharov TP, Darzi A. Framework for systematic training and assessment of technical skills. *Journal of the American College of Surgeons*. 2007;204(4):697-705.
9. Ahlberg G, Enochsson L, Gallagher AG, et al. Proficiency-based virtual reality training significantly reduces the error rate for residents during their first 10 laparoscopic cholecystectomies. *The American journal of surgery*. 2007;193(6):797-804.
10. Chaer RA, DeRubertis BG, Lin SC, et al. Simulation improves resident performance in catheter-based intervention: results of a randomized, controlled study. *Annals of surgery*. 2006;244(3):343.
11. Hart R, Doherty DA, Karthigasu K, Garry R. The value of virtual reality-simulator training in the development of laparoscopic surgical skills. *Journal of minimally invasive gynecology*. 2006;13(2):126-133.
12. Kneebone R. Simulation in surgical training: educational issues and practical implications. *Medical education*. 2003;37(3):267-277.
13. Sutherland LM, Middleton PF, Anthony A, et al. Surgical simulation: a systematic review. *Annals of surgery*. 2006;243(3):291.
14. Tavakol M, Mohagheghi MA, Dennick R. Assessing the skills of surgical residents using simulation. *Journal of surgical education*. 2008;65(2):77-83.
15. Martin J, Regehr G, Reznick R, et al. Objective structured assessment of technical skill (OSATS) for surgical residents. *British journal of surgery*. 1997;84(2):273-278.
16. Reznick R, Regehr G, MacRae H, Martin J, McCulloch W. Testing technical skill via an innovative "bench station" examination. *The American Journal of Surgery*. 1997;173(3):226-230.
17. Van Heest A, Putnam M, Agel J, Shanedling J, McPherson S, Schmitz C. Assessment of technical skills of orthopaedic surgery residents performing open carpal tunnel release surgery. *JBJS*. 2009;91(12):2811-2817.
18. Vassiliou MC, Feldman LS, Andrew CG, et al. A global assessment tool for evaluation of intra-operative laparoscopic skills. *The American journal of surgery*. 2005;190(1):107-113.
19. Aggarwal R, Grantcharov T, Moorthy K, Milland T, Darzi A. Toward feasible, valid, and reliable video-based assessments of technical surgical skills in the operating room. *Annals of surgery*. 2008;247(2):372-379.
20. Moorthy K, Munz Y, Sarker SK, Darzi A. Objective assessment of technical skills in surgery. *Bmj*. 2003;327(7422):1032-1037.
21. Satterwhite T, Son J, Carey J, et al. Microsurgery education in residency training: validating an online curriculum. *Annals of plastic surgery*. 2012;68(4):410-414.
22. Anastakis DJ, Regehr G, Reznick RK, et al. Assessment of technical skills transfer from the bench training model to the human model. *The American journal of surgery*. 1999;177(2):167-170.
23. Palter VN, Grantcharov TP. Simulation in surgical education. *Canadian Medical Association Journal*. 2010;182(11):1191-1196.

24. Dimick JB, Scott JW. A Video Is Worth a Thousand Operative NotesA Video Is Worth a Thousand Operative NotesResearch. 2019.
25. Celentano V, Smart N, McGrath J, et al. LAP-VEGaS practice guidelines for reporting of educational videos in laparoscopic surgery: a joint trainers and trainees consensus statement. *Annals of surgery*. 2018;268(6):920-926.
26. Ritter EM. Invited Editorial LAP-VEGaS Practice Guidelines for Video-based Education in Surgery: Content is Just the Beginning. *Annals of surgery*. 2018;268(6):927-929.
27. Yee A, Padovano WM, Fox IK, et al. Video-Based Learning in Surgery: Establishing Surgeon Engagement and Utilization of Variable-Duration Videos. *Annals of Surgery*. 2019;(Accepted).
28. Zhang D, Zhou L, Briggs RO, Nunamaker Jr JF. Instructional video in e-learning: Assessing the impact of interactive video on learning effectiveness. *Information & management*. 2006;43(1):15-27.
29. Goldman R, Pea R, Barron B, Derry SJ. *Video research in the learning sciences*. Routledge; 2014.
30. Al Abbas AI, Jung JP, Rice MK, Zureikat AH, Zeh III HJ, Hogg ME. Methodology for Developing an Educational and Research Video Library in Minimally Invasive Surgery. *Journal of surgical education*. 2019.
31. Ericsson KA. Necessity is the mother of invention: video recording firsthand perspectives of critical medical procedures to make simulated training more effective. *Academic Medicine*. 2014;89(1):17-20.
32. Ericsson KA. Acquisition and maintenance of medical expertise: a perspective from the expert-performance approach with deliberate practice. *Academic Medicine*. 2015;90(11):1471-1486.
33. Topps D, Helmer J, Ellaway R. YouTube as a platform for publishing clinical skills training videos. *Academic Medicine*. 2013;88(2):192-197.
34. Lee Z-H, Reavey PL, Rodriguez ED, Chiu ES, Caplan AL. Ethical Issues in Aesthetic and Reconstructive Surgical Innovation: Perspectives of Plastic Surgeons. *Plastic and reconstructive surgery*. 2019;143(1):346-351.
35. Sterodimas A, Radwanski HN, Pitanguy I. Ethical issues in plastic and reconstructive surgery. *Aesthetic plastic surgery*. 2011;35(2):262-267.
36. Jayakumar N, Brunckhorst O, Dasgupta P, Khan MS, Ahmed K. e-Learning in surgical education: a systematic review. *Journal of surgical education*. 2015;72(6):1145-1157.
37. Tarpada SP, Morris MT, Burton DA. E-learning in orthopedic surgery training: a systematic review. *Journal of orthopaedics*. 2016;13(4):425-430.
38. Tarpada SP, Hsueh WD, Gibber MJ. Resident and student education in otolaryngology: A 10-year update on e-learning. *The Laryngoscope*. 2017;127(7):E219-E224.
39. Maertens H, Madani A, Landry T, Vermassen F, Van Herzeele I, Aggarwal R. Systematic review of e-learning for surgical training. *British Journal of Surgery*. 2016;103(11):1428-1437.
40. Niitsu H, Hirabayashi N, Yoshimitsu M, et al. Using the Objective Structured Assessment of Technical Skills (OSATS) global rating scale to evaluate the skills of surgical trainees in the operating room. *Surgery today*. 2013;43(3):271-275.
41. Mackinnon SE, Novak CB. Compression Neuropathies. In: Wolfe SW, Pederson WC, Kozin SH, eds. *Green's Operative Hand Surgery*. 6th ed. Churchill Livingstone, Philadelphia PA: Elsevier Health Sciences; 2010.
42. Schuenke M, Schulte E, Schumacher U. *General Anatomy and Musculoskeletal System (THIEME Atlas of Anatomy)*. Thieme; 2011.
43. Mackinnon SE, Yee A. Carpal Tunnel Release. Washington University Learn Surgery. learnsurge.wustl.edu. Published 2013. Accessed March 3, 2019.
44. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychological bulletin*. 1979;86(2):420.
45. Goh AC, Goldfarb DW, Sander JC, Miles BJ, Dunkin BJ. Global evaluative assessment of robotic skills: validation of a clinical assessment tool to measure robotic surgical skills. *The Journal of Urology*. 2012;187(1):247-252.
46. Kardas M, O'Brien E. Easier seen than done: Merely watching others perform can foster an illusion of skill acquisition. *Psychological science*. 2018.
47. Reznick RK, MacRae H. Teaching surgical skills—changes in the wind. *New England Journal of Medicine*. 2006;355(25):2664-2669.
48. Scott DJ, Bergen PC, Rege RV, et al. Laparoscopic training on bench models: better and more cost effective than operating room experience? 1. *Journal of the American College of Sur-*

- geons. 2000;191(3):272-283.
49. Johnson-Laird PN. *Mental models: Towards a cognitive science of language, inference, and consciousness*. Harvard University Press; 1983.
50. De Kleer J, Brown JS. Assumptions and ambiguities in mechanistic mental models. In: *Mental models*. Psychology Press; 2014:163-198.
51. Mayer RE, Gallini JK. When is an illustration worth ten thousand words? *Journal of educational psychology*. 1990;82(4):715.
52. Moulton C-a, Regehr G, Lingard L, Merritt C, MacRae H. Slowing down to stay out of trouble in the operating room: remaining attentive in automaticity. *Academic Medicine*. 2010;85(10):1571-1577.
53. Betrancourt M. The animation and interactivity principles in multimedia learning. *The Cambridge handbook of multimedia learning*. 2005:287-296.
54. Katz AJ. The role of crowdsourcing in assessing surgical skills. *Surgical Laparoscopy Endoscopy & Percutaneous Techniques*. 2016;26(4):271-277.
55. Polin MR, Siddiqui NY, Comstock BA, et al. Crowdsourcing: a valid alternative to expert evaluation of robotic surgery skills. *American journal of obstetrics and gynecology*. 2016;215(5):644.e641-644. e647.
56. Powers MK, Boonjindasup A, Pinsky M, et al. Crowdsourcing assessment of surgeon dissection of renal artery and vein during robotic partial nephrectomy: a novel approach for quantitative assessment of surgical performance. *Journal of endourology*. 2016;30(4):447-452.
57. Palmer AK, Toivonen DA. Complications of endoscopic and open carpal tunnel release. *The Journal of hand surgery*. 1999;24(3):561-565.
58. Plana NM, Rifkin WJ, Kantar RS, et al. A Prospective, Randomized, Blinded Trial Comparing Digital Simulation to Textbook for Cleft Surgery Education. *Plastic and reconstructive surgery*. 2019;143(1):202-209.
59. Alfonso AR, Ramly EP, Gonchar M, et al. Cleft Surgery Knowledge and Skills Acquisition by Plastic Surgery Residents: A Simulation-Based Prospective, Randomized, Blinded Trial. 64th Annual Meeting Plastic Surgery Research Council; May 3, 2019; Baltimore, MD.

CHAPTER 4

EFFECTIVENESS OF VIDEO-BASED LEARNING IN TEACHING CLINICAL REASONING FOR CUBITAL TUNNEL SURGERIES

Based on:

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* Joint first authors

ABSTRACT

OBJECTIVE

To evaluate the effectiveness of an online video-based learning module in teaching management of cubital tunnel syndrome to include a new surgical procedure to improve fine motor hand function, and to describe an evidence-based framework for module design.

BACKGROUND

In a landmark 2010 report, the National Academy of Medicine identified major deficits in the continuing medical education (CME) system in the United States. It called for a transition toward a system of continuing professional development (CPD), which emphasizes long-term, sustainable practice change. The report highlighted online multimedia (e-learning) as a promising strategy for CPD. However, the feasibility, acceptability, and long-term impact of using videos to learn clinical reasoning in surgery remain poorly understood.

METHODS

An online educational module was developed to teach patient selection for cubital tunnel surgeries, including the supercharge end-to-side (SETS) anterior interosseous to ulnar motor nerve transfer. It consisted of a mandatory baseline knowledge assessment, choice of two self-guided video lectures (7-minutes and 28-minutes), and an optional post-lecture knowledge assessment. An additional assessment distributed 3 months after module completion examined knowledge retention. Surveys administered during these assessments assessed baseline practices, practice change, and perceived value of the module.

RESULTS

A total of 279 surgeons participated in the educational module (75% practicing physicians, 7.5% fellows, 17.5% residents). Among practicing surgeons, 93% offered surgery for cubital tunnel syndrome, and 32% specifically offered the SETS nerve transfer. Median score on the pre-test assessment was 5 out of 10. A majority of participants (84%) watched the full-lecture video, and most reported spending at least 30 minutes watching one or both lectures. Knowledge assessment scores improved by 3 points ($p < 0.0001$) immediately following the lecture(s). Knowledge retention persisted at 3 months after module completion, and 68% reported that the module changed how they managed cubital tunnel syndrome.

CONCLUSIONS

Video-based learning is an effective strategy for promoting continuing professional development among extremity surgeons. The educational module was well-received, led to substantial improvement in knowledge among both practicing surgeons and trainees, and supported potential long-term practice change.

INTRODUCTION

Clinical judgment, or clinical reasoning, is an essential part of surgery. It encompasses all phases of patient management, from initial workup to post-operative care and follow-up.¹⁻⁴ Both technical expertise and clinical judgment are necessary for achieving optimal quality of care.⁵ Moreover, new procedures rely on a shared understanding of indications to ensure safe implementation and reduce variability in surgical outcomes.^{6,7} While multiple educational studies have examined novel ways to enhance and evaluate technical performance,⁸ comparatively little attention has focused on means of teaching clinical judgment.⁹

In the United States, surgeons have traditionally evolved with changing trends and advancements in their fields through peer-reviewed literature and decentralized continuing medical education (CME) activities.¹⁰ However, a 2010 report by the National Academy of Medicine identified irreconcilable flaws in the current approach to CME, concluding that it “fails to deliver the most useful and important health information to health professionals, leaving them unable to adopt evidence-based approaches.”¹¹ The report called for a transition away from CME and towards a system of continuing professional development (CPD), which emphasizes long-term practice change. Several recommendations included (1) facilitating self-directed learning outside of professional activities, (2) using learning theories to develop educational interventions, (3) analyzing the effectiveness of these interventions, and (4) improving the value and cost-effectiveness of continuing education. Online multimedia learning (e-learning) was highlighted as a promising strategy for CPD, since it is inexpensive, highly accessible, and allows providers to learn at their own pace.¹²⁻¹⁶ Despite these intuitive applications in CPD, few studies have examined the effectiveness of online multimedia or formalized design principles for this modality.^{17,18}

While the roles of video in disseminating and learning technical skills have been demonstrated,^{19,20} learning clinical judgment through video-based education has not been evaluated. The aims of this study were (1) to evaluate the effectiveness of an online video-based learning module in teaching management of cubital tunnel syndrome to include a new surgical procedure to improve fine motor hand function, and (2) to describe an evidence-based framework for module design. Through longitudinal surveys, we assessed surgeon attitudes, practice change, and potential barriers to adoption of e-learning for surgical education.

METHODS

An online video-based learning module was developed to teach surgeons an evidence-based algorithm for diagnosis and management of ulnar neuropathy from cubital tunnel syndrome (Fig. 4.1).²¹ Extremity surgeons were solicited via email from the members of *Washington University Learn Surgery* (learnsurgery.wustl.edu) and *DocMatter* (docmatter.com) over a one-month period. The module was approved by an accredited CME office to provide 0.75 AMA PRA Category 1 Credit and Self-Assessment Credit towards ABS MOC Part 2 – Lifelong Learning & Self-Assessment. The study design was approved by our institutional review board (#201805057).

FIGURE 4.1. Study design of educational video module. Surgeons were solicited from members of Washington University Learn Surgery and DocMatter. Participants completed a pre-study evaluation, given two videos (abridged and full-lecture), and completed a post-lecture and 3-month retention evaluations. Participants who did not complete the post-lecture evaluation provided study feedback by describing barriers to completion. Summary of incorrect answers, CME credit, and the answer key with exclusive video access were provided to participants following completion of the respective evaluations as incentives.

EDUCATIONAL MODULE DESIGN

The educational module consisted of (1) a choice of two variable-length, self-guided video lectures and (2) knowledge assessments administered before (mandatory, pre-lecture assessment) and after (optional, post-lecture assessment) watching the lectures. After completion of the pre-lecture assessment, incorrect answers were displayed to participants to preface learning before the lectures. All answers with clinical reasoning were emailed following the post-lecture assessment. Development of the module and videos were guided by the cognitive theory of multimedia learning (CTML) and spatial learning using concept mapping.^{22,23} CTML describes at least 12 evidence-based principles for managing cognitive load and enhancing knowledge acquisition,²⁴⁻²⁹ which were explicitly addressed in the design of the module and lecture (Table 4.1).

The online lectures consisted of a 28-minute (full-length) video and a 7-minute (abridged) video developed using *Prezi* (prezi.com; Budapest, Hungary) and uploaded to *YouTube* (youtube.com; San Bruno, CA). The module was developed using *SurveyGizmo* (surveygizmo.com; Boulder, CO) and included embedded links to the *YouTube* videos. Video analytics, which included views, watch-time, and engagement,¹⁹ were collected from *YouTube Creator Studio* (youtube.com/creatorstudio).

Knowledge assessments were accompanied by surveys that evaluated training experience, practice setting, learning satisfaction, current practices, intent to change practice, and time spent on the module. Another knowledge assessment and survey were administered 3-months following module completion to examine knowledge retention and practice change.

CONTENT OF VIDEO LECTURES AND KNOWLEDGE ASSESSMENTS

The lectures summarized a recent decision algorithm for cubital tunnel syndrome,^{21,30} which incorporated electrodiagnostic and clinical findings (Fig. 4.2). Specifically, the algorithm described when to trial conservative management and when to perform an ulnar nerve release or transposition, Guyon's canal release, and supercharge end-to-side (SETS) anterior interosseus to ulnar motor nerve transfer. Teaching interpretation of electrodiagnostic studies included the clinical significance of reduced conduction velocity, reduced compound muscle action potential (CMAP) amplitude, reduced sensory nerve action potential (SNAP) amplitude, acute and chronic motor unit potentials (MUPs), the presence of fibrillations and positive sharp waves, and the relevance of a conduction block. Participants were guided through multiple clinical cases to practice interpreting electrodiagnostic studies and exemplify use of the treatment algorithm. Knowledge assessments consisted of 10 multiple-choice questions that evaluated the correct use of electrodiagnostic studies in managing cubital tunnel syndrome. CME credit was awarded to participants who answered at least 8 out of the 10 questions (75%) correctly on the post-lecture assessment. Following completion of the module, participants were given unrestricted access to both lecture videos.

TABLE 4.1 Evidence-based principles guided by the cognitive theory of multimedia learning.

Principles	Description	Application in Module
Managing Cognitive Load		
Pre-training	Prime learner with relevant definitions and questions	Baseline knowledge assessment and providing knowledge deficit to learner
Modality	Augment images with narration	Narrated video using clinical expert performance
Coherence	Minimize distractions and irrelevant information	Minimalist instructional design used to display specific and relevant information
Spatial contiguity	Cluster related words and images together	Diagrams and concept maps of information used to facilitate spatial learning
Temporal contiguity	Synchronize animations with narration	Narrator emphasizes parts of the decision algorithm with a virtual pointer
Segmentation	Split a topic into segments and allow learners to control progression through them	Topics detailing operative context and learning clinical reasoning were separated using concept maps
Enhancing Generative Processing		
Personalization	Use conversational language	Language in script was informal and directed to practicing surgeons
Variability	Provide multiple different examples	Several clinical example cases were used to emphasize different paths in a decision algorithm
<u>Worked-example</u>	Guide learners through a complete solution	A decision algorithm for each clinical example case was gradually completed
Interactivity	Allow learners to navigate through different segments of an animation	Participants controlled progression through a decision algorithm and self-directed module
Completion	Encourage learners to complete a partially solved example	Provided CME credit, answer key with thorough explanations, and exclusive access to the videos upon module completion
Self-explanation	Prompt learners to apply new information	Post-lecture and retention knowledge assessments

EVALUATION OF BARRIERS TO MODULE COMPLETION

A survey was sent to participants who began the module but did not complete the post-lecture assessment despite 3 reminder emails. Survey questions evaluated barriers to participation (e.g. time investment, dislike assessments, access issues, etc.) and perceived value of the module.

STATISTICAL ANALYSES

Power and sample size estimates were informed by multiple studies evaluating the effects of internet-based CME activities.³¹⁻³⁵ On a 10-point scale, we assumed that participants would on average score 1-point higher on the retention assessment than on the pre-lecture assessment, that scores would have a pooled standard deviation of 2 points, and that performances would have a moderate correlation of 0.4. We further expected that 50% of those completing the educational module would complete the retention assessment. Consequently, using a paired two-sided t-test, we assumed that 80 participants would need to complete the educational module for 80% power to detect a 1-point improvement in assessment scores at a 0.05 level of significance.

Responses to each question in the pre-lecture and post-lecture assessments were compared by McNemar or Wilcoxon signed-rank tests, where appropriate. Summative scores were calculated for the pre-lecture, post-lecture, and retention assessments, and scores were compared by Wilcoxon signed-rank test. The influence of training level and setting on assessment scores and the impact of re-watching videos in the months prior to completing the retention assessment were evaluated by Wilcoxon rank-sum test. False discovery rate adjustment was performed to correct for multiple statistical comparisons. All analyses were performed using SAS (version 9.4) and adjusted p-values less than 0.05 were considered statistically significant.

RESULTS

A total of 279 surgeons participated in the educational module, including 209 practicing surgeons (75%), 21 fellows (7.5%), and 49 residents (17.5%). Among practicing surgeons, 42% considered their practice academic, and 93% performed surgery for cubital tunnel syndrome. Specifically, 32% have performed the SETS nerve transfer for patients with cubital tunnel syndrome and 27% were considering adding this procedure to their practice. Median score on the pre-lecture assessment was 5 out of 10, with practicing surgeons scoring 1-point higher than trainees (0.005). Practice setting (academic vs. private) did not influence scores ($p=0.16$).

A total of 112 surgeons (72% practicing surgeons, 28% trainees) completed the post-lecture assessment and 78 surgeons (85% practicing surgeons, 15% trainees) were awarded CME. There was no significant difference in pre-lecture scores between these surgeons and those who did not complete the post-lecture assessment ($p=0.27$). Median post-lecture assessment score was 9 out of 10, with no significant

difference between practicing surgeons and trainees ($p=0.88$). Individual scores improved by 3 points ($p<0.0001$) (Table 4.2), with participants being significantly more likely to answer all but one of the assessment questions correctly. The majority of participants (84%) reported watching the full-length format of the lecture (52% watched only the full-length format and 32% watched both formats), and most participants (54%) reported spending at least 30 minutes watching one or both videos (Fig. 4.3).

TABLE 4.2. Pre- and post-lecture and retention assessment scores.

Questions	Percent Answered Correctly* (%)		
	Pre-lecture	Post-lecture	<i>p</i> -value†
Electrodiagnostic Subsection			
EDX indication for localization of nerve injury	70	98	<0.0001
EDX indication for severity of nerve injury	32	90	<0.0001
EDX indication for receptivity of motor endplates	57	97	<0.0001
Identification of conduction block	23	68	<0.0001
Supercharge End-to-side (SETS) Nerve Transfer Subsection			
Correct patient selection for SETS nerve transfer	14	67	<0.0001
Requirements for SETS Nerve Transfer:			
A. Weak intrinsic muscles: required	74	97	0.0002
B. Reduced CMAP amplitude at the elbow: not required	45	84	<0.0001
C. Reduced CMAP amplitude at wrist: required	55	91	<0.0001
D. Fibrillations and positive sharp waves in intrinsic muscles: required	72	98	<0.0001
E. Normal donor nerve: required	98	100	1.00

* Among participants who responded in both the pre- and post-lecture assessments

† Bonferroni adjusted *p*-values

Three months following completion of the module, 71 surgeons (75% practicing surgeons, 25% trainees) completed the knowledge retention assessment. Median score on the retention assessment was 8 out of 10, with participants significantly maintaining a 2-point increase from their pre-lecture score ($p=0.0002$), but experiencing a 1-point decrease from their post-lecture score ($p=0.001$). However, of the 30% of respondents who reported re-watching the lectures in the intervening months, surgeons retained their knowledge with no significant difference between post-lecture and retention scores ($p=0.88$).

FIGURE 4.3. Time spent watching the video lectures. Participants self-reported the time spent watching the abridged and/or full-lecture videos.

In the post-lecture survey, 99% of surgeons reported that the intervention improved their knowledge, and 90% anticipated that it would change their practice. Among 41% of surgeons who were not initially interested in the SETS nerve transfer, 78% indicated that they would consider adding this procedure to their practice after completing the module. Of those completing the retention survey, 68% confirmed that the module had changed their management of cubital tunnel syndrome (17% undecided, 15% reported no change). Additionally, 76% of surgeons preferred the online educational module over a traditional conference presentation, and 96% felt that the knowledge assessments enhanced their learning when compared to watching the lecture(s) alone.

During the entire extent of the study, the full-length lecture received a total of 507 views with an average watch-time per session of 10.8 minutes (39% engagement), while the abridged lecture received 285 views, with an average watch-time per session of 4.0 minutes (57% engagement). Accounting for self-reported viewing patterns, these metrics suggest that viewers of each format, on average, watched the lecture over two viewing sessions. Furthermore, relative audience retention described sustained above average viewing engagement when compared to all *YouTube* videos with peaks and troughs of interests throughout the abridged and full-length lectures (Fig. 4.4).

Among the 167 surgeons who started the module but did not complete the post-lecture assessment, 27 (16%) completed a survey assessing barriers to completion. The most commonly cited barrier was having limited time (70%), and 7% reported disliking self-assessments. Nonetheless, 83% of respondents stated that the intervention changed how they manage cubital tunnel syndrome.

DISCUSSION

Extremity surgery has evolved rapidly over the past decades, and the number and complexity of surgical options for nerve injuries continues to grow. Gaining experience with a new operative technique requires an understanding of when and to whom to offer it, also known as clinical judgment. Inappropriate patient selection for a nerve transfer, for example, may result in an unsuccessful or unnecessary procedure and donor site morbidity without any functional benefit. While interpretation of electrodiagnostic studies is typically with the purview of neurologists, it is the authors' experience that a practical understanding of electrodiagnostic studies assists in operative planning for most nerve injury conditions.

Tasked with increasingly difficult clinical decisions, it is essential that surgeons continue to develop at the pace of surgical advancements. Unfortunately, the impact of traditional means of CME, such as lectures and seminars at national conferences, on actual clinical practice is controversial,^{36,37} and new teaching modalities remain incompletely understood.³¹ To address this knowledge gap, surgeon educators must (1) establish methods to reproducibly measure effectiveness and (2) develop minimally disruptive means of including such evaluations in teaching materials.

MEASURING EFFECTIVENESS OF A VIDEO-BASED LEARNING MODULE

Here, effectiveness is defined in accordance to *Key Questions* of the American College of Chest Physicians (ACCP): (1) imparting knowledge, (2) changing attitudes, and (3) changing practice behaviors.^{31,38} Additional categories beyond the scope of our investigation are (4) technical skills acquisition and (5) improvements in clinical outcomes. While nearly all surgeons in this study offered cubital tunnel surgery, they typically answered only half of pre-lecture assessment questions correctly. We emphasize that this does not imply deficiencies in technical ability nor in management of cubital tunnel syndrome. Indeed, the intent of this module was not to evaluate whether surgeons were providing standard of care, but to refine patient selection for an innovative procedure (SETS nerve transfer) that was first introduced in 2011.^{21,39,40} Nonetheless, knowledge substantially improved after the module, and these gains were maintained for at least 3 months. Surgeons were also more likely to consider performing the SETS nerve transfer following the module, and most reported changes in clinical practice 3 months after module completion.

Measuring the impact of an educational modality facilitates an understanding of

how to design future resources. Moreover, the use of learning theory and reporting frameworks promote these resources for other surgical topics. To this end, the educational module was developed in accordance with the Ellaway's Framework for e-Learning Research.⁴¹ Its design, including the combination of knowledge assessments and dynamic video lectures, was guided by CTML and spatial learning using concept maps,^{23,26,42,43} which provides several empirically-supported principles for improving the effectiveness of multimedia interventions. These include guiding the learner through cases, also known as worked-examples (Table 4.1), using conversational speech, and giving the learner navigational control.⁴⁴⁻⁴⁶ Content was developed by expert opinion leaders to promote practice change,^{47,48} in accordance to diffusion of innovation theory and social cognitive theory.⁴⁹⁻⁵²

While employing CTML has improved learning among medical students,^{27,53} it was unknown if surgeons see value in self-assessments or expend considerable time required to watch a full-length lecture. Indeed, conventional teaching maintains that educational or surgical videos should be limited to 10 minutes or less,^{24,29} although we have recently disputed this length constraint.¹⁹ We demonstrate that most surgeons spent at least 30 minutes learning and, on average, returned to the lecture(s) to watch it over two viewing sessions. Respondents also overwhelmingly supported the use of practical self-assessments. While this may represent a selection bias, in which surgeons who completed the assessments may be more likely to see value in such assessments, only a minority of those not finishing the module reported disliking self-assessments. Encouragingly, a third of learners who completed the retention assessment had returned to re-watch the videos despite not receiving any CME credit for repeat views. These findings imply an interest among surgeons to engage in self-directed learning to reinforce and maintain their knowledge.

ADVANCING CLINICAL JUDGMENT IN LEARNING TECHNICAL SKILL

Over the past decade, our group has developed a framework for the design and dissemination of high-quality surgical videos to improve technical skill.^{19,20} The educational program consisted of operative videos describing nerve surgery and included innovative techniques, such as the SETS nerve transfer.^{11,39,54} While the purpose of these videos was to convey operative nuances, even with masterful surgical technique, optimal results can only be achieved through appropriate patient selection and sound clinical judgment. Refining indications for the SETS nerve transfer in cubital tunnel syndrome required review of clinical outcomes, as well as studying the electrodiagnostic features of compression neuropathy.²¹ These efforts led to a proposed revision in how cubital tunnel syndrome is classified to include CMAP amplitude as an indicator of axonal loss and disease severity,^{55,56} rather than a traditional decrease in conduction velocity at the elbow.³⁰

Teaching patient selection for cubital tunnel surgery, or clinical judgment in general, is conceptually distinct from teaching operative details. In the context of educational theory, teaching clinical judgment is grounded on several fundamental

Relative Audience Retention of Abridged and Full-length Video Lectures

FIGURE 4.4. Relative audience retention of abridged and full-length video lectures. Relative audience retention describes the peaks and troughs of viewing interest when compared to all YouTube videos. Sustained above average engagement occurred in both lectures, however a prominent trough of viewing interest was seen at the beginning of the severe compression section describing the SETS nerve transfer. Black notches indicate time-stamped slide transitions during the lecture.

principles to describe the value of deliberate exposure to real cases and depict polymorphisms of actual clinical material encountered in everyday practice.⁵⁷ Defining contextual factors within these cases is an important principle that improves performance.⁵⁸⁻⁶⁰ Additionally, clinical judgment relies on the interplay of two processes: system 1 thinking, which is fast and often subconscious, and system 2 thinking, which is slower and requires conscious effort.⁶¹⁻⁶³ Within this framework, novices typically rely more heavily on system 2 as they acclimate managing a new condition, whereas experts rely more heavily on the automated processing of system 1 in their decision-making. A strategy to integrate clinical judgment through this model of decision-making is to reduce cognitive load in the presented materials and use rich-narration.^{62,64} The goal of our educational module was to incorporate these systems to promote acquisition of clinical judgment using videos.⁶⁵ In this module, a diagnostic algorithm served as a focal point to visually present and linearly progress through worked-examples of real cases. Explaining nerve pathophysiology and its manifestations on electrodiagnostic studies also provided the contextual basis for the algorithm. Encouraging the learner to consider *why* a specific treatment was recommended will help transition the learner from a novice clinician to an expert.

FUTURE DIRECTIONS

The intent of this investigation was to neither demonstrate nor imply that online multimedia should, in all cases, replace conference proceedings or text-based resources. Studies comparing online multimedia to traditional educational resources, such as live lectures, have shown mixed results.^{66,67} In the authors' view, such discussions are of limited value to the CPD of surgeons. Nonetheless, as the field of nerve surgery continues to develop and video-based learning becomes increasingly prevalent among surgical trainees,^{68,69} it is likely that online multimedia will play an increasingly prominent role in surgical education. This modality offers several intuitive advantages to traditional strategies, such as reduced financial, gender, and geographic barriers to expert teaching, unlimited access for just-in-time learning, self-assessments that can be scored in real-time, and self-guided lectures.^{31,37} It offers new opportunities to both speed the spread of innovative procedures and ensure their safe implementation.⁷⁰

LIMITATIONS

Participation in the online educational module was completely voluntary. This may have produced a selection bias in which surgeons choosing to complete the module had a more favorable view of multimedia education than those who did not. However, there was no difference in performance in the pre-lecture assessment between those who did and did not complete the post-lecture assessment. Both groups of surgeons felt that the module had influenced how they manage cubital tunnel syndrome. Having established the effectiveness of video-based learning in teaching clinical judgment, future studies may evaluate important implementation outcomes, such as its acceptability, appropriateness, and adoption of this modality.⁷¹ As this was a survey study, we were also unable to confirm self-reported practice change or

measure differences in clinical outcomes. This limitation is shared by several studies evaluating multimedia learning.³¹

CONCLUSION

This novel study establishes the utility of evidence-based principles of using video-based learning for continuing professional development in surgery. It also underscores a demand among surgeons for easily accessible, reusable, and self-paced educational resources. Similar online modules may be developed to address this need and to facilitate the dissemination of clinical judgment.

REFERENCES

1. Durning SJ, Artino AR, Jr., Schuwirth L, van der Vleuten C. Clarifying assumptions to enhance our understanding and assessment of clinical reasoning. *Acad Med*. 2013;88(4):442-448.
2. Higgs J, Jones M, Loftus S, Christensen N. *Clinical Reasoning in the Health Professions*. 3rd ed. Boston, MA: Elsevier Health Sciences; 2008.
3. Elstein AS, Schwartz A. Clinical problem solving and diagnostic decision making: selective review of the cognitive literature. *BMJ*. 2002;324(7339):729-732.
4. Elstein AS, Shulman LS, Sprafka SA. *Medical Problem Solving: an Analysis of Clinical Reasoning*. Cambridge, MA: Harvard University Press; 1978.
5. Ericsson KA. An expert-performance perspective of research on medical expertise: the study of clinical performance. *Med Educ*. 2007;41(12):1124-1130.
6. Hirst A, Philippou Y, Blazeby J, et al. No Surgical Innovation Without Evaluation: Evolution and Further Development of the IDEAL Framework and Recommendations. *Ann Surg*. 2019;269(2):211-220.
7. Hull L, Athanasiou T, Russ S. Implementation Science: A Neglected Opportunity to Accelerate Improvements in the Safety and Quality of Surgical Care. *Ann Surg*. 2017;265(6):1104-1112.
8. Dawe SR, Pena GN, Windsor JA, et al. Systematic review of skills transfer after surgical simulation-based training. *Br J Surg*. 2014;101(9):1063-1076.
9. Kempton SJ, Bentz ML. Making master surgeons out of trainees: Part I. Teaching surgical judgment. *Plastic and reconstructive surgery*. 2016;137(5):1646-1653.
10. Curran VR, Fleet LJ, Kirby F. A comparative evaluation of the effect of Internet-based CME delivery format on satisfaction, knowledge and confidence. *BMC Med Educ*. 2010;10:10.
11. *Institute of Medicine - Committee on Planning a Continuing Health Care Professional Education Institute. Redesigning continuing education in the health professions*. National Academies Press; 2010.
12. Brydges R, Carnahan H, Safir O, Dubrowski A. How effective is self-guided learning of clinical technical skills? It's all about process. *Med Educ*. 2009;43(6):507-515.
13. Brydges R, Dubrowski A, Regehr G. A new concept of unsupervised learning: directed self-guided learning in the health professions. *Acad Med*. 2010;85(10 Suppl):S49-55.
14. Brydges R, Nair P, Ma I, Shanks D, Hatala R. Directed self-regulated learning versus instructor-regulated learning in simulation training. *Med Educ*. 2012;46(7):648-656.
15. Murad MH, Coto-Yglesias F, Varkey P, Prokop LJ, Murad AL. The effectiveness of self-directed learning in health professions education: a systematic review. *Med Educ*. 2010;44(11):1057-1068.
16. Mazmanian P, Feldman M. Theory is needed to improve education, assessment and policy in self-directed learning. *Med Educ*. 2011;45(4):324-326.
17. McMahon GT. Advancing continuing medical education. *Jama*. 2015;314(6):561-562.
18. Shortt S, Guillemette JM, Duncan AM, Kirby F. Defining quality criteria for online continuing medical education modules using modified nominal group technique. *Journal of Continuing Education in the Health Professions*. 2010;30(4):246-250.
19. Yee A, Padovano WM, Fox IK, et al. Video-Based Learning in Surgery: Establishing Surgeon Engagement and Utilization of Variable-duration Videos. *Ann Surg*. 2019(In-press).
20. Yee A, Padovano WM, Rowe AG, et al. The Role of Surgical Video on Resident Performance of Carpal Tunnel Release: A Cadaveric Simulation-based, Prospective, Randomized, Blinded Pilot Study. *Plast Reconstr Surg*. 2019(Accepted).
21. Power HA, Kahn LC, Patterson MM, Yee A, Moore AM, Mackinnon SE. Refining indications for the supercharge end-to-side anterior interosseous to ulnar motor nerve transfer in cubital tunnel syndrome. *Plast Reconstr Surg*. 2019;In-press.
22. Mayer RE. Cognitive theory of multimedia learning. *The Cambridge handbook of multimedia learning*. 2005;43.
23. Daley BJ, Torre DM. Concept maps in medical education: an analytical literature review. *Med Educ*. 2010;44(5):440-448.
24. Ritter EM. Invited Editorial LAP-VEGaS Practice Guidelines for Video-based Education in Surgery: Content is Just the Beginning. *Annals of surgery*. 2018;268(6):927-929.
25. Mayer RE. Applying the science of learning: Evidence-based principles for the design of multimedia instruction. *American psychologist*. 2008;63(8):760.
26. Sorden SD. The cognitive theory of multimedia learning. *Handbook of educational theories*.

- 2012;1.
27. Yue C, Kim J, Ogawa R, Stark E, Kim S. Applying the cognitive theory of multimedia learning: an analysis of medical animations. *Medical education*. 2013;47(4):375-387.
28. Ayres P, Paas F. Cognitive load theory: New directions and challenges. *Applied Cognitive Psychology*. 2012;26(6):827-832.
29. Prober CG, Khan S. Medical education reimaged: a call to action. *Acad Med*. 2013;88(10):1407-1410.
30. Power HA, Sharma K, El-Haj M, Moore AM, Patterson MM, Mackinnon SE. Compound Muscle Action Potential Amplitude Predicts the Severity of Cubital Tunnel Syndrome. *J Bone Joint Surg Am*. 2019;101(8):730-738.
31. Marinopoulos SS, Dorman T, Ratanawongsa N, et al. Effectiveness of continuing medical education. *Evid Rep Technol Assess (Full Rep)*. 2007;149(1):1-69.
32. Meredith LS, Jackson-Triche M, Duan N, Rubenstein LV, Camp P, Wells KB. Quality Improvement for Depression Enhances Long-term Treatment Knowledge for Primary Care Clinicians. *Journal of General Internal Medicine*. 2000;15(12):868-877.
33. Premi J, Shannon SI. Randomized controlled trial of a combined video-workbook educational program for CME. *Academic Medicine*. 1993;68(10):S13-15.
34. Stewart M, Marshall JN, Ostbye T, et al. Effectiveness of case-based on-line learning of evidence-based practice guidelines. *Fam Med*. 2005;37(2):131-138.
35. Fordis M, King JE, Ballantyne CM, et al. Comparison of the instructional efficacy of Internet-based CME with live interactive CME workshops: a randomized controlled trial. *JAMA*. 2005;294(9):1043-1051.
36. Sachdeva AK. The new paradigm of continuing education in surgery. *Archives of Surgery*. 2005;140(3):264-269.
37. Nissen SE. Reforming the continuing medical education system. *JAMA*. 2015;313(18):1813-1814.
38. Marinopoulos SS, Baumann MH. Methods and definition of terms: effectiveness of continuing medical education: American College of Chest Physicians Evidence-Based Educational Guidelines. *Chest*. 2009;135(3):17S-28S.
39. Kale SS, Glaus SW, Yee A, et al. Reverse end-to-side nerve transfer: from animal model to clinical use. *J Hand Surg Am*. 2011;36(10):1631-1639 e1632.
40. Davidge KM, Yee A, Moore AM, Mackinnon SE. The Supercharge End-to-Side Anterior Interosseous-to-Ulnar Motor Nerve Transfer for Restoring Intrinsic Function: Clinical Experience. *Plast Reconstr Surg*. 2015;136(3):344e-352e.
41. Ellaway R. Apples and architraves: a descriptive framework for e-learning research. *Medical teacher*. 2010;32(1):95-97.
42. Kirschner F, Kester L, Corbalan G. Cognitive load theory and multimedia learning, task characteristics, and learning engagement: The current state of the art. 2010.
43. Paas F, Sweller J. Implications of cognitive load theory for multimedia learning. *The Cambridge handbook of multimedia learning*. 2014;27:27-42.
44. Brame CJ. Effective educational videos: Principles and guidelines for maximizing student learning from video content. *CBE—Life Sciences Education*. 2016;15(4):es6.
45. Gordon M, Chandratilake M, Baker P. Low fidelity, high quality: a model for e-learning. *The clinical teacher*. 2013;10(4):258-263.
46. Grunwald T, Corsbie-Massay C. Guidelines for cognitively efficient multimedia learning tools: educational strategies, cognitive load, and interface design. *Academic medicine*. 2006;81(3):213-223.
47. Damschroder LJ, Aron DC, Keith RE, Kirsh SR, Alexander JA, Lowery JC. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. *Implementation science*. 2009;4(1):50.
48. Ericsson KA. Acquisition and maintenance of medical expertise: a perspective from the expert-performance approach with deliberate practice. *Acad Med*. 2015;90(11):1471-1486.
49. Bandura A. Social cognitive theory for personal and social change by enabling media. In: *Entertainment-education and social change*. Routledge; 2003:97-118.
50. Brownson RC, Colditz GA, Proctor EK. *Dissemination and implementation research in health: translating science to practice*. Oxford University Press; 2018.
51. Kaufman DM. Applying educational theory in practice. *Bmj*. 2003;326(7382):213-216.
52. Sanson-Fisher RW. Diffusion of innovation theory for clinical change. *Medical journal of Australia*. 2004;180:S55-S56.

53. Issa N, Schuller M, Santacaterina S, et al. Applying multimedia design principles enhances learning in medical education. *Medical education*. 2011;45(8):818-826.
54. Barbour J, Yee A, Kahn LC, Mackinnon SE. Supercharged end-to-side anterior interosseous to ulnar motor nerve transfer for intrinsic musculature reinnervation. *J Hand Surg Am*. 2012;37(10):2150-2159.
55. Qing C, Zhang J, Wu S, et al. Clinical classification and treatment of cubital tunnel syndrome. *Exp Ther Med*. 2014;8(5):1365-1370.
56. Watanabe M, Arita S, Hashizume H, Honda M, Nishida K, Ozaki T. Multiple regression analysis for grading and prognosis of cubital tunnel syndrome: assessment of Akahori's classification. *Acta Med Okayama*. 2013;67(1):35-44.
57. Kassirer JP. Teaching clinical reasoning: case-based and coached. *Acad Med*. 2010;85(7):1118-1124.
58. Durning S, Artino AR, Jr., Pangaro L, van der Vleuten CP, Schuwirth L. Context and clinical reasoning: understanding the perspective of the expert's voice. *Med Educ*. 2011;45(9):927-938.
59. McBee E, Ratcliffe T, Picho K, et al. Consequences of contextual factors on clinical reasoning in resident physicians. *Adv Health Sci Educ Theory Pract*. 2015;20(5):1225-1236.
60. McBee E, Ratcliffe T, Picho K, et al. Contextual factors and clinical reasoning: differences in diagnostic and therapeutic reasoning in board certified versus resident physicians. *BMC Med Educ*. 2017;17(1):211.
61. Kahneman D. *Thinking, fast and slow*. New York, NY: Farrar, Straus and Giroux; 2011.
62. Djulbegovic B, Hozo I, Beckstead J, Tsalatsanis A, Pauker SG. Dual processing model of medical decision-making. *BMC Med Inform Decis Mak*. 2012;12:94.
63. Tversky A, Kahneman D. Judgment under uncertainty: Heuristics and biases. *Science*. 1974;185(4157):1124-1131.
64. Bizzocchi J, Schell R. Rich-narrative case study for online PBL in medical education. *Acad Med*. 2009;84(10):1412-1418.
65. van Gog T, Rummel N. Example-based learning: Integrating cognitive and social-cognitive research perspectives. *Educational Psychology Review*. 2010;22(2):155-174.
66. Spickard A, 3rd, Alrajeh N, Cordray D, Gigante J. Learning about screening using an online or live lecture: does it matter? *J Gen Intern Med*. 2002;17(7):540-545.
67. Chao SH, Brett B, Wiecha JM, Norton LE, Levine SA. Use of an online curriculum to teach delirium to fourth-year medical students: a comparison with lecture format. *J Am Geriatr Soc*. 2012;60(7):1328-1332.
68. Ahmet A, Gamze K, Rustem M, Sezen KA. Is Video-Based Education an Effective Method in Surgical Education? A Systematic Review. *J Surg Educ*. 2018;3(75):1150-1158.
69. Rapp AK, Healy MG, Charlton ME, Keith JN, Rosenbaum ME, Kapadia MR. YouTube is the Most Frequently Used Educational Video Source for Surgical Preparation. *J Surg Educ*. 2016;73(6):1072-1076.
70. Colditz GA, Brownson R, Proctor E. The promise and challenges of dissemination and implementation research. *Dissemination and implementation research in health: Translating science to practice*. 2012:3-22.
71. Proctor E, Silmere H, Raghavan R, et al. Outcomes for implementation research: conceptual distinctions, measurement challenges, and research agenda. *Administration and Policy in Mental Health and Mental Health Services Research*. 2011;38(2):65-76.

PART II

ADDRESSING ANATOMICAL ETHICS IN SURGICAL INNOVATION

CHAPTER 5

THE ROLE OF EDUARD PERNKOPF'S ATLAS OF HUMAN ANATOMY IN SURGICAL PRACTICE

NERVE SURGEONS AND ORAL & MAXILLOFACIAL SURGEONS' ASSESSMENT

Based on:

Yee A, Coombs DM, Hildebrandt S, Seidelman WE, Coert JH, Mackinnon SE. Nerve Surgeon's Assessment of the Role of Eduard Pernkopf's Atlas of Topographic and Applied Human Anatomy in Surgical Practice. *Neurosurgery*. 2019 Feb 1;84(2):491-498.

Yee A, Li J, Lilly J, Hildebrandt S, Seidelman WE, Brown D, Kopar P, Mackinnon SE, Israel HA. Oral and Maxillofacial Surgeon's Assessment of the Role of Pernkopf's Atlas in Surgical Practice. [Under Review]

ABSTRACT

OBJECTIVE

To assess the role of Pernkopf's atlas in nerve surgeons and oral & maxillofacial surgeons' current practice and determine whether an ethical proposal to highlight the history of the atlas could provide possible guidance for its use in surgery and surgical education.

BACKGROUND

Pernkopf's Atlas of Anatomy contains anatomical plates with detailed images of the peripheral nerves. Its use is controversial due to the author's association with the Third Reich and the potential depiction of victims of the Holocaust. The ethical implications of using this atlas for informing surgical planning have not been assessed.

METHODS

Five surgical societies (nerve surgery and oral & maxillofacial surgery) were surveyed and 364 responses collected. The survey introduced the historical origin of Pernkopf's atlas and respondents were asked whether they would use the atlas under specific conditions to serve as a recommendation for its ethical handling. An anatomical plate comparison between Netter's and Pernkopf's atlases was performed to compare anatomical accuracy and surgical utility.

RESULTS

Fifty-nine percent (59%) of nerve surgery and 49% of oral & maxillofacial surgery respondents were aware of Pernkopf's atlas, and respectively, 13% and 18% were currently using it. Aware of the historical facts, 69% and 42% were comfortable using the atlas, 15% and 33% uncomfortable, and 17% and 25% undecided. Additional information on conditions for an ethical approach to the use of the atlas led 76% and 75% of those "uncomfortable" and "undecided" to becoming "comfortable" with use.

CONCLUSIONS

While the use of Pernkopf's atlas remains controversial, a proposal detailing conditions for an ethical approach in its use provides new guidance in surgical planning and education.

INTRODUCTION

Eduard Pernkopf's *Atlas of Topographical and Applied Human Anatomy* was first published in its German version between 1937 and 1960, and the first American version in 1963. Publication ceased in 1994 due to the revelation in the mid-1980s and 1990s of the author's participation in the National Socialist (Nazi) regime and the possible use of executed victims from the Third Reich.²⁻⁹ The atlas was widely known by anatomists and surgeons for its intricacy and "regional stratigraphic" approach, which involves multiple layers of dissection from superficial to deep, with an emphasis on fascial relationships that are often missing from comparable anatomical atlases.¹⁰ Because of its historical connection with the criminal Nazi regime, Pernkopf's atlas has been the basis of ethics discussions surrounding its use as teaching material in the anatomical sciences¹¹⁻¹⁴, but continues to circulate as a used book, and is anecdotally known for providing anatomical utility in some surgical communities. This presents ethical challenges for its use in patients who need complex surgery.¹⁵ The purpose of this study is to (1) assess the role of Pernkopf's atlas in nerve surgeons and oral & maxillofacial surgeons' current practice and (2) determine whether an ethical proposal to highlight the history of the atlas could provide possible guidance for its use in surgery and surgical education.

5

Eduard Pernkopf (1888-1955) and the atlas's illustrators were devoted members of the Nazi party (NSDAP, *Nationalsozialistische Deutsche Arbeiterpartei*) and/or soldiers in World War II.⁹ Pernkopf, the Director of the Viennese Anatomical Institute, was appointed as Dean of the Medical Faculty in 1938, directly after the annexation of Austria by Nazi Germany, and served as President of the University of Vienna from 1943-1945.⁷ In his role as Dean, he oversaw the dismissal of 157 of the 197 members of the medical faculty. Most emigrated, some died at their own hand or were murdered in concentration camp.¹⁶ The medical illustrators demonstrated their Nazi allegiance by including Swastikas and lightning-bolt SS (*Schutzstaffel*) symbols in their signatures on the paintings.⁹ Pernkopf's and the illustrators' significant Nazi involvement was confirmed in an investigation of the origin of the bodies depicted in the paintings, which was authorized by the Senate of the University of Vienna in 1998.⁴

This Senatorial Project was designed to include an outside consultant (Albin Eser) and resemble an earlier historical self-assessment by an anatomical institute (University of Tübingen) with the objectives to (1) investigate the origin and destiny of the bodies used by Pernkopf and (2) determine the extent of his Nazi party membership and political activities.⁶ The findings of the Senatorial Project revealed 3,964 bodies of adults were unclaimed, 7 donated, and at least 1,377 bodies were executed prisoners, who were victims of the Nazis' unjust legislation. There was no evidence that bodies were sourced from concentration camps close to Vienna, despite such bodies being transported to a different Austrian anatomical institute.^{5,6} Of the 791 illustrations produced for the atlas, 41 plates were "highly likely" based on the bodies of executed victims, with the origin of approximately 350 plates remaining unclear.⁵ While traditional, legal anatomical body procurement included unclaimed bodies from public institutions, among them executed prisoners and persons who

committed suicide, the number of executions rose exponentially under the Nazi regime due to new legislation.¹⁷

Because of this history, the use of Pernkopf's atlas for complex surgical planning presents significant ethical challenges.^{14,15} Furthermore, an assessment of the current role of the atlas in a surgeon's practice does not exist. This study represents a focused assessment in nerve surgery and oral & maxillofacial surgery due to the intricate portrayal of complex nerve and maxillofacial anatomy in Pernkopf's atlas. While anatomical atlases vary widely with respect to detail, dissection, topography, artistic rendition, and overall design,^{3,18-25} Pernkopf's atlas has been considered as a "masterpiece" in the anatomical sciences, even if indeed a "troubled masterpiece."⁹

A goal of this investigation is to assess whether Pernkopf's atlas provides anatomical accuracy and surgical utility, as judged by nerve surgeons and oral & maxillofacial surgeons, in comparison with another prominent and well-known atlas (Netter's *Atlas of Human Anatomy*) through a visual plate comparison.²⁶ In a next step, surgeons were informed about a proposal for a potential ethically justified use of Pernkopf's atlas and asked, if this information would change their decision to "use" or "not to use" the atlas. This proposal is based on recent discussions on the handling of human remains and data from the Holocaust era, discussions that included the Pernkopf paintings.^{1,27,28} The findings from this study serve as a recommendation from surgeons for the ethical handling of Pernkopf's atlas in surgery.

METHODS

SELECTION & DESCRIPTION OF PARTICIPANTS

An electronic questionnaire was designed using an online survey tool (SurveyGizmo, surveygizmo.com) and distributed via email to nerve surgeon members of the American Society for Peripheral Nerve (ASPN) and PASSIO Education (passioeducation.com), and oral & maxillofacial surgeon members of the American College of Oral and Maxillofacial Surgeons (ACOMS), American Society of Temporomandibular Joint Surgeons (ASTMJS), and American Association of Oral and Maxillofacial Surgeons (AAOMS). Data collection for nerve surgery occurred from April 10th, 2017 through July 7th, 2019 and for oral & maxillofacial surgery from February 16, 2018 through December 8, 2018. Recruitment of participants was performed by an initial email invitation to each group (ASPN, PASSIO; ACOMS, ASTMJS, AAOMS), followed by two reminder emails before the survey was closed. No incentives for survey participation were offered. This study (#201702009) was approved by the Institutional Board of Washington Review University School of Medicine in St. Louis, MO.

STUDY DESIGN

The survey was composed of two parts: (1) surgical assessment and ethical handling of Pernkopf's atlas and (2) demographics, anatomical resources, and anatomical plate comparisons. The first part included a maximum of 11 questions with embedded survey logic to prevent exposure of repeated questions to reduce survey fatigue. Respondents were exposed to the historical findings of the Senatorial Project for assessment.⁴⁻⁶ Special consideration was given to avoid exposure to Pernkopf illustrations for individuals who responded as being "uncomfortable" with the use of the atlas. Following the assessment, participants were given a scenario for a decision to "use" or "not to use" if certain ethical conditions were met. A "4-point proposal" was developed, which includes (1) formal disclosure discussing the historical origin and ethical challenges, (2) consensus from bioethicists validating its specific use for benefiting the lives of patients, (3) consensus from *Bet Din* (Jewish religious rabbinical court) that is consistent with the Jewish principle, *Piku'ach nefesh*, which describes, under certain conditions, the preservation of human life overrides any other religious consideration,¹ and (4) an official memorial commemorating the victims portrayed in the atlas. Responses from the previous assessment were compared to responses following the 4-point proposal to determine its effectiveness.

5

The second survey part included a maximum of 10 demographic and 2 anatomical resource questions and 6 plate comparisons for nerve surgery and 4 plate comparisons for oral & maxillofacial surgery. Ten plates were selected,²⁶ each from Netter's and Pernkopf's atlases^{3,20} that demonstrated comparable structures, anatomical orientation, and relevance to nerve surgery to ensure a standardized comparison. Images were scanned at high-resolution, identifiable labels removed, and "white-balanced" to ensure proper image quality. Before the plate comparison, participants underwent a descriptive tutorial with an optional video and logic question to ensure the appropriate computer skill to view both Netter's and Pernkopf's plate. Netter's and Pernkopf's plates were randomized with either left or right positioning in each comparison. An estimated length of 12 minutes was calculated for completion of the entire survey.

STATISTICAL ANALYSIS

All statistical analyses (*p*-values) on the plate comparison data were performed using SPSS Statistical Software (version 23, IBM, Armonk, NY). Proportions of surgeons, who perceived images as having greater anatomical accuracy and greater surgical utility, were given the null hypothesis of 50/50.

RESULTS

DEMOGRAPHICS

Nerve Surgery

182 responses were collected (25% response rate, 77% completion rate, 35% ASPN, 65% PASSIO). Of the respondents, 83% were male and 17% female; ages ranged from 26-73 years old; 16% were resident physicians, 12% surgical fellows, and 72% practicing surgeons. Additional demographic data pertaining to continent-of-origin, race, religious beliefs, surgical specialty, and years-of-practice were obtained (Table 5.1).

Oral & Maxillofacial Surgery

181 responses were collected (9% response rate, 80% completion rate, 64% ACOMS, 15% ASTMJS, 21% AAOMS). Of the respondents, 90% were male and 10% female; ages ranged from 26-94 years old; 10% were resident physicians, 4% surgical fellows, and 86% practicing surgeons. Additional demographic data pertaining to continent-of-origin, race, religious beliefs, surgical specialty, and years-of-practice were obtained (Table 5.1).

AWARENESS AND USAGE OF PERNKOPF'S ATLAS

Nerve Surgery

Of the respondents, 59% were aware of Pernkopf's atlas. Of those *aware*, 41% had used it previously; 22% were currently using it; 77% were aware of the atlas's historical origin (Table 5.2). Of those *historically aware of the origin of the atlas*, 66% reported "some general knowledge" concerning the abusive actions of German physicians during the Third Reich with 10% and 24% respectively reporting having "very little" or a "great deal" of knowledge. These numbers are similar for practicing surgeons and trainees, except for 31% of practicing surgeons reporting knowing a "great deal" compared to only 6% of trainees.

Oral & Maxillofacial Surgery

Of the respondents, 49% were aware of Pernkopf's atlas. Of those *aware*, 57% had used it previously; 18% were currently using it; 64% were aware of the atlas's historical origin (Table 5.3). Of those *historically aware of the origin of the atlas*, 58% reported "some general knowledge" concerning the abusive actions of German physicians during the Third Reich with 4% and 38% respectively reporting having "very little" or a "great deal" of knowledge. A majority of trainees (74%) were not aware of Pernkopf's atlas compared to the mostly split-even awareness in practicing surgeons.

TABLE 5.1. Demographics of survey respondents.

Demographics	Nerve Surgery	Oral & Maxillofacial Surgery
Gender	Proportion (%)	
Male	83	90
Female	17	10
Age	Years	
Age	26-73 (avg. 43)	26-94 (avg. 54)
Continent of Origin	Proportion (%)	
North America	45	78
South America	5	1
Europe	27	13
Asia	16	7
Africa	5	0
Australia	2	1
Race	Proportion (%)	
Asian	13	7
Black	1	0
East Indian	2	0
Latino/Hispanic	8	4
Middle Eastern	9	1
White	63	79
Bi-racial	1	1
Multi-racial	4	1
Other	1	3
Religious Beliefs	Proportion (%)	
Agnostic	14	3
Atheist	11	5
Buddhist/Taoist	2	0
Christian (Catholic, Orthodox, Protestant, Latter Day Saints, Other)	39	51
Hindu	4	1
Jewish	13	27
Muslim/Islam	10	1
Spiritual	4	3
Prefer Not to Answer	1	7
Other	2	0
Position	Proportion (%)	
Resident or Fellow Surgeon	26	14
Practicing Surgeon	64	86
Surgical Specialty / Practice Type	Proportion (%)	
Hand Surgery	55	-
Neurological Surgery	19	-
Orthopedic Surgery	28	-
Plastic and Reconstructive Surgery	45	-
Other	7	-
Oral and Maxillofacial Surgeons	-	100
Practice Duration	Years	
Years-in-Practice	1-39 (avg. 14)	1-65 (avg. 25)

TABLE 5.2. Survey responses to use or not to use Pernkopf's atlas in nerve surgery.

Survey Questions	Total N = 182		Practicing Surgeons N = 108		Surgical Trainees N = 42		Jewish N = 20	
	Yes	No	Yes	No	Yes	No	Yes	No
Are you aware of Eduard Pernkopf's Atlas of Topographical and Applied Human Anatomy?	59%	41%	57%	43%	52%	48%	65%	35%
L Have you previously used Pernkopf's atlas?	41%	59%	45%	55%	41%	59%	39%	62%
L Are you currently using Pernkopf's atlas?	22%	79%	23%	77%	18%	82%	8%	92%
L Are you aware of the history behind the creation of Pernkopf's atlas?	77%	23%	77%	23%	82%	18%	92%	8%
Little, some, great deal								
L What is your level of knowledge concerning the improper actions of some German physicians during the Third Reich?	10%, 66%, 24%		8%, 60%, 31%		17%, 78%, 6%		0%, 42%, 58%	
L Do you prefer to use an alternative anatomical resource because of your knowledge of the history of Pernkopf's atlas?	Yes	No	Yes	No	Yes	No	Yes	No
	29%	71%	35%	65%	6%	94%	75%	25%
Historical Presentation of Pernkopf's Atlas of Topographical and Applied Human Anatomy								
Yes, undecided, no								
Based upon this information, would you be comfortable using Pernkopf's atlas as a reference material?	69%, 17%, 15%		62%, 18%, 20%		81%, 17%, 2%		40%, 15%, 45%	
Would you use Pernkopf's atlas if which of the following conditions are met:	Use	Not Use	Use	Not Use	Use	Not Use	Use	Not Use
L A formal and educational disclosure displayed prior to viewing the atlas discussing its historical origin and ethical discussion.	38%		32%		55%		25%	
L A consensus from bioethics validating its specific use for benefiting the lives of patients.	31%		25%		38%		10%	
L A consensus validating its use from Bet Din (Jewish religious rabbinical court) and consistent with the Jewish ethical principle of <i>Pikeuach Nafesh</i> in that preservation of human life overrides virtually any other religious consideration.	17%		14%		24%		15%	
L An official memorial existed, which was dedicated to the victims of the atlas.	20%		16%		29%		15%	
L All of the above.	22%		22%		19%		30%	
L None of the above. I would use Pernkopf's atlas regardless of the above conditions.	29%		32%		19%		10%	
L None of the above. I would NOT use Pernkopf's atlas		10%		8%		0%		25%
Comfortable, undecided, uncomfortable, no opinion								
a Given the controversial history of Pernkopf's atlas and having met all ethical and moral conditions provided above, how would you feel about specific Pernkopf's plates to accompany a surgical education resource as important anatomical landmarks with specific conditions?	81%, 8%, 6%, 6%		77%, 7%, 10%, 6%		88%, 5%, 0%, 7%		47%, 13%, 27%, 7%	
Yes, undecided, no								
b Given the controversial history of Pernkopf's atlas and having met all ethical and moral conditions provided above, would you allow for the specific use of the atlas by other surgeons in the treatment of patients with devastating nerve injuries?	33%, 11%, 56%		33%, 22%, 44%		No responses		20%, 60%, 20%	
L – Survey logic which displays the question to the participant based on the previous proper question (e.g. “yes” to the “awareness” question displays the question of “previous use”). Therefore, denoted survey answers are a subpopulation of the previous proper question (e.g. “41% yes” to “previous use” question is a subpopulation of the “59% yes” of the “awareness” question).								
a – Survey logic specific to the “use” group.								
b – Survey logic specific to the “not use” group.								

TABLE 5.3. Survey responses to use or not to use Pernkopf's atlas in oral & maxillofacial surgery.

Survey Questions	Total N = 181		Practicing Surgeons N = 140		Surgical Trainees N = 23		Jewish N = 48	
	Yes	No	Yes	No	Yes	No	Yes	No
Are you aware of Eduard Pernkopf's Atlas of Topographical and Applied Human Anatomy?	49%	51%	56%	44%	26%	74%	71%	29%
L Have you previously used Pernkopf's atlas?	57%	43%	59%	41%	50%	50%	59%	41%
L Are you currently using Pernkopf's atlas?	18%	82%	21%	79%	0%	100%	15%	85%
L Are you aware of the history behind the creation of Pernkopf's atlas?	64%	36%	64%	36%	50%	50%	82%	18%
Little, some, great deal								
L What is your level of knowledge concerning the improper actions of some German physicians during the Third Reich?	4%, 58%, 38%		4%, 58%, 38%		0%, 33%, 67%		4%, 46%, 50%	
	Yes	No	Yes	No	Yes	No	Yes	No
L Do you prefer to use an alternative anatomical resource because of your knowledge of the history of Pernkopf's atlas?	65%	35%	64%	36%	67%	33%	79%	21%
Historical Presentation of Pernkopf's Atlas of Topographical and Applied Human Anatomy								
Yes, undecided, no								
Based upon this information, would you be comfortable using Pernkopf's atlas as a reference material?	42%, 25%, 33%		43%, 24%, 33%		39%, 35%, 26%		27%, 27%, 46%	
Would you use Pernkopf's atlas if which of the following conditions are met:	Use	Not Use	Use	Not Use	Use	Not Use	Use	Not Use
L A formal and educational disclosure displayed prior to viewing the atlas discussing its historical origin and ethical discussion.	45%		43%		61%		60%	
L A consensus from bioethics validating its specific use for benefiting the lives of patients.	43%		43%		48%		52%	
L A consensus validating its use from Bet Din (Jewish religious rabbinical court) and consistent with the Jewish ethical principle of <i>Pikeuach Nafesh</i> in that preservation of human life overrides virtually any other religious consideration.	22%		21%		22%		29%	
L An official memorial existed, which was dedicated to the victims of the atlas.	23%		24%		22%		33%	
L All of the above.	29%		33%		4%		31%	
L None of the above. I would use Pernkopf's atlas regardless of the above conditions.	13%		13%		9%		2%	
L None of the above. I would NOT use Pernkopf's atlas	19%		19%		13%		19%	
Comfortable, undecided, uncomfortable, no opinion								
a Given the controversial history of Pernkopf's atlas and having met all ethical and moral conditions provided above, how would you feel about specific Pernkopf's plates to accompany a surgical education resource as important anatomical landmarks with specific conditions?	64%, 20%, 9%, 7%		64% 7%, 7%, 22%		70%, 10%, 15%, 5%		55%, 28%, 15%, 2%	
Yes, undecided, no								
b Given the controversial history of Pernkopf's atlas and having met all ethical and moral conditions provided above, would you allow for the specific use of the atlas by other surgeons in the treatment of patients with devastating nerve injuries?	33%, 26%, 41%		38%, 24%. 38%		33%, 0%, 67%		11%, 11%, 78%	
L – Survey logic which displays the question to the participant based on the previous proper question (e.g. “yes” to the “awareness” question displays the question of “previous use”). Therefore, denoted survey answers are a subpopulation of the previous proper question (e.g. “57% yes” to “previous use” question is a subpopulation of the “49% yes” of the “awareness” question).								
a – Survey logic specific to the “use” group.								
b – Survey loaic specific to the “not use” group.								

INFLUENCE OF A 4-POINT ETHICAL PROPOSAL

Nerve Surgery

Following an explanation of the history surrounding Pernkopf's atlas, 69% of respondents felt comfortable using it as reference material, with 17% undecided and 15% uncomfortable (Fig. 5.1, top). Respondents were then asked if they would use Pernkopf's atlas under any of four ethical conditions: (1) 38% would "use" the atlas in conjunction with a formal and educational disclosure prior to viewing the atlas, (2) 31% with having a consensus from bioethicists validating its use to benefit patient care, (3) 17% after a *Bet Din* consensus validating *Piku'ach nefesh*,¹ (4) 20% with having an official memorial commemorating the victims of the atlas, and 22% with having met all of the above conditions; 29% of respondents would use Pernkopf's atlas regardless of those conditions; and finally 6% of respondents would not use Pernkopf's atlas irrespective of those conditions. Of the respondents who were initially "undecided" or "uncomfortable" in using the atlas, 93% and 59% respectively changed their decision to "use" of the atlas following the 4-point proposal, with an average of 76%.

Oral & Maxillofacial Surgery

Following an explanation of the history surrounding Pernkopf's atlas, 42% of respondents felt comfortable using it as reference material, with 25% undecided and 33% uncomfortable (Fig. 5.1, bottom). Respondents were then asked if they would use Pernkopf's atlas under any of four ethical conditions: (1) 45% would "use" the atlas in conjunction with a formal and educational disclosure prior to viewing the atlas, (2) 43% with having a consensus from bioethicists validating its use to benefit patient care, (3) 22% after a *Bet Din* consensus validating *Piku'ach nefesh*,¹ (4) 23% with having an official memorial commemorating the victims of the atlas, and 29% with having met all of the above conditions; 13% of respondents would use Pernkopf's atlas regardless of those conditions; and finally 13% of respondents would not use Pernkopf's atlas irrespective of those conditions. Of the respondents who were initially "undecided" or "uncomfortable" in using the atlas, 98% and 52% respectively changed their decision to "use" of the atlas following the 4-point proposal, with an average of 75%.

SURGICAL EDUCATION AND USE BY OTHERS TO BENEFIT PATIENTCARE

Nerve Surgery

Respondents, who were comfortable with the use of the atlas following the 4-point proposal, were then asked whether the images could be used to teach important anatomical landmarks alongside the surgical videos on PASSIO Education (passioeducation.com), if the following conditions were met: (1) no financial profit would be made from the images, (2) the images could not be downloaded, (3) full disclosure in a preface documenting the historical origin and ethical challenges of Pernkopf's atlas, and (4) a hyperlink to the official information and memorial relating to the atlas; 81% reported being comfortable, 8% undecided, 6% uncomfortable, and 6% no

Nerve Surgery

Based upon the historical information, how would you feel about using Pernkopf's atlas?

Would you use Pernkopf's atlas if which of the following 4-point ethical considerations are met?

Oral and Maxillofacial Surgery

Based upon the historical information, how would you feel about using Pernkopf's atlas?

Would you use Pernkopf's atlas if which of the following 4-point ethical considerations are met?

FIGURE 5.1. Graphical assessment of Pernkopf's atlas in nerve surgery (top) and oral & maxillofacial surgery (bottom) and the influence of the 4-point ethical proposal on the use of Pernkopf's atlas for surgery and education. (Left) Respondents were asked whether they were comfortable, undecided, uncomfortable for using Pernkopf's atlas following a historical presentation. (Right) Afterwards, respondents were asked under which of the following ethical conditions they would use Pernkopf's atlas: (1) 38%, 45% reported use with a formal and educational disclosing the atlas's historical origin and ethical challenges, (2) 31%, 43% with a consensus from bioethicists validating the specific use for benefiting the lives of patients, (3) 17%, 22% with a consensus from Bet Din (Jewish religious rabbinical court) that is consistent with the Jewish principle, Piku'ach nefesh, which describes, under certain conditions, the preservation of human life overrides any other religious consideration, (4) 20%, 23% with an official memorial dedicated to the victims of the atlas, and 22%, 29% with all the above conditions. Respondents who were initially "undecided" or "uncomfortable" transitioned to "use" following the 4-point proposal by 93%, 98% and 59%, 52% respectively.

opinion. Respondents, who would not use the atlas despite the 4-point proposal, were asked whether they would allow other surgeons to use the atlas to benefit patients with devastating nerve injuries; 33% reported yes, 56% no, and 11% were undecided.

Oral & Maxillofacial Surgery

Respondents, who were comfortable with the use of the atlas following the 4-point proposal, were then asked whether the images could be used to teach important anatomical landmarks alongside the surgical videos on an online video-based learning program, if the following conditions were met: (1) no financial profit would be made from the images, (2) the images could not be downloaded, (3) full disclosure in a preface documenting the historical origin and ethical challenges of Pernkopf's atlas, and (4) a hyperlink to the official information and memorial relating to the atlas; 64% reported being comfortable, 20% undecided, 9% uncomfortable, and 7% no opinion. Respondents, who would not use the atlas despite the 4-point proposal, were asked whether they would allow other surgeons to use the atlas to benefit patients with devastating nerve injuries; 33% reported yes, 26% no, and 41% were undecided.

RESPONSES FROM SURGEONS OF JEWISH DESCENT

Nerve Surgery

Respondents who identified as being of Jewish descent (N=20, 13%) were analyzed independently on their awareness, usage, and influence of the 4-point proposal. This step was taken because Jews were the main target of Nazi extermination policies in the Holocaust and thus potentially most affected by the use of the atlas.^{29,30} Of the respondents with Jewish descent, thirteen (65%) were aware of Pernkopf's atlas. Of those aware, five (39%) had used it previously; one (8%) was currently using it, and twelve (92%) were aware of the atlas's historical origin. Of those historically aware of the origin of the atlas, 58% reported knowing a "great deal" concerning the abusive actions of German physicians during the Third Reich, with the remaining 42% having "some general knowledge." Following a historical explanation of Pernkopf's atlas, 40% felt comfortable using it as reference material, with 15% undecided and 45% uncomfortable. Respondents were then provided with the 4-point proposal. Most agreed to the conditional "use" of the images, with 25% after a formal and educational disclosure, 10% following a bioethicists consensus, 15% after a *Bet Din* consensus validating *Piku'ach nefesh*,¹ 15% in conjunction with an official memorial, and 30% if all conditions were met; 10% of respondents would use Pernkopf's atlas regardless of those conditions; 25% of respondents would not use Pernkopf's atlas irrespective of those conditions.

Oral & Maxillofacial Surgery

Respondents who identified as being of Jewish descent (N=48, 26%) were analyzed independently on their awareness, usage, and influence of the 4-point proposal. This step was taken because Jews were the main target of Nazi extermination policies in the Holocaust and thus potentially most affected by the use of the atlas.^{29,30} Of the respondents with Jewish descent, 71% were aware of Pernkopf's atlas. Of

those *aware*, 59% had used it previously; 15% were currently using it, and 82% were aware of the atlas’s historical origin. Of those *historically aware of the origin of the atlas*, 50% reported knowing a “great deal” concerning the abusive actions of German physicians during the Third Reich, with the remaining 46% having “some general knowledge.” Following a historical explanation of Pernkopf’s atlas, 27% felt comfortable using it as reference material, with 27% undecided and 46% uncomfortable. Respondents were then provided with the 4-point proposal. Most agreed to the conditional “use” of the images, with 60% after a formal and educational disclosure, 52% following a *bioethicists* consensus, 29% after a *Bet Din* consensus validating *Piku’ach nefesh*,¹ 33% in conjunction with an official memorial, and 31% if all conditions were met; one respondent would use Pernkopf’s atlas regardless of those conditions; 19% of respondents would not use Pernkopf’s atlas irrespective of those conditions.

USE OF ANATOMICAL RESOURCES AND ATLASES

Nerve Surgery

All respondents were asked about the type of anatomical resources they used (Table 5.4). Eighty-one percent (81%) reported the use of anatomical atlases, 86% specialized surgical textbooks, 65% original research/clinical journal articles, 29% societal educational resources, and 76% internet resources. Of the anatomical atlases,^{3,18-25} 81% reported using Netter’s atlas, 50% Gray’s atlas, 33% Grant’s atlas, 24% Sobotta’s atlas, 14% Thieme’s atlas, 13% Pernkopf’s atlas, 12% Rohen’s atlas, 7% Lippincott Williams and Wilkins’ atlas, and 1% Morris’ atlas (Table 5.5).

Oral & Maxillofacial Surgery

All respondents were asked about the type of anatomical resources they used (Table 5.4). Sixty-nine percent (69%) reported the use of anatomical atlases, 79% specialized surgical textbooks, 50% original research/clinical journal articles, 19% societal educational resources, and 56% internet resources. Of the anatomical atlases,^{3,18-25} 59% reported using Netter’s atlas, 42% Gray’s atlas, 40% Grant’s atlas, 2% Sobotta’s atlas, 3% Thieme’s atlas, 10% Pernkopf’s atlas, 3% Rohen’s atlas, 7% Lippincott Williams and Wilkins’ atlas, and 3% Morris’ atlas (Table 5.5).

TABLE 5.4. Types of anatomical resources used in nerve surgery and oral & maxillofacial surgery.

Type of Anatomical Resources Used	Nerve Surgery	Oral & Maxillofacial Surgery
	Proportion	
Anatomical Atlases	81%	69%
Specialized Surgical Textbooks	86%	79%
Original Research & Clinical Journal Articles	65%	50%
Societal Educational Resources	29%	19%
Internet Resources	76%	56%
Other	4%	4%

TABLE 5.5. Types of anatomical atlases used in nerve surgery and oral & maxillofacial surgery.

Type of Anatomical Atlases Used	Nerve Surgery	Oral & Maxillofacial Surgery
	Proportion	
Netter's Atlas of Human Anatomy	81%	59%
Gray's Atlas of Anatomy	50%	42%
Grant's Atlas of Human Anatomy	33%	40%
Sobotta's Atlas of Human Anatomy	24%	2%
Thieme's Atlas of Anatomy	14%	3%
Pernkopf's Atlas of Topographical & Applied Human Anatomy	13%	10%
Rohen's Photographic Color Atlas of Anatomy	12%	3%
Other	11%	3%
Lippincott Williams & Wilkins' Atlas of Anatomy	7%	7%
Morris' Human Anatomy: A Complete Systematic Treatise	1%	3%

NETTER VS. PERNKOPF ANATOMICAL PLATE COMPARISONS

Nerve Surgery

Respondents, who were “comfortable” with the use of Pernkopf’s atlas following the 4-point proposal, were given 6 sets of comparisons between similar Netter’s and Pernkopf’s plates (Table 5.6). The six comparisons were prefaced with an emphasis of anatomical nerve structures listed in Table 5.6. The respondents found Pernkopf’s atlas having both greater anatomical detail (range 79-91%) and greater utility for surgery (range 66-82%) when compared with Netter’s ($p < 0.001$) in all plate comparisons.

Oral & Maxillofacial Surgery

Respondents, who were “comfortable” with the use of Pernkopf’s atlas following the 4-point proposal, were given 4 sets of comparisons between similar Netter’s and Pernkopf’s plates (Table 5.6). The six comparisons were prefaced with an emphasis of anatomical nerve structures listed in Table 5.6. The respondents found Pernkopf’s atlas having both greater anatomical detail (range 76-91%) and greater utility for surgery (range 76-81%) when compared with Netter’s ($p < 0.001$) in all plate comparisons.

DISCUSSION

No systematic study exists that documents the use of Pernkopf’s atlas in surgery either in the past or present. Even though the former publisher Urban & Schwarzenberg stopped publication of the work in 1994, there is anecdotal evidence that the atlas is still being used. The historical connection between the book and the Nazi regime presents ethical challenges in its use for intraoperative surgical planning.^{14,15} This study presents an assessment of the use of the atlas by nerve surgeons and oral & maxillofacial surgeons, as well as an evaluation of the potential ethical implications involved.

TABLE 5.6. Comparison of anatomical plates: Pernkopf vs. Netter

Anatomical Plate Description	Plate		Greater Anatomical Detail			Greater Surgical Utility		
	P	N	Pernkopf	Netter	p-value	Pernkopf	Netter	p-value
Nerve Surgery								
Facial nerve and distal branches.	140	20	91%	5%	$p < 0.001$	82%	14%	$p < 0.001$
Spinal accessory, brachial plexus, and phrenic nerves.	285	28	90%	6%	$p < 0.001$	75%	21%	$p < 0.001$
Axillary nerve and its superior lateral cutaneous branch in relation to the radial nerve.	50	415	86%	7%	$p < 0.001$	82%	13%	$p < 0.001$
Palmar and digital cutaneous branches of the median and ulnar nerves.	77	443	82%	6%	$p < 0.001$	80%	13%	$p < 0.001$
Subcostal, iliohypogastric, ilioinguinal, genitofemoral, and lateral femoral cutaneous nerves.	186	259	79%	12%	$p < 0.001$	66%	20%	$p < 0.001$
Femoral nerve and its distal branches and the saphenous nerve in relation to anteromedial intermuscular septum.	347	482	91%	6%	$p < 0.001$	79%	15%	$p < 0.001$
Oral & Maxillofacial Surgery								
Deep facial anatomy from lateral view after resection of zygomatic arch and ramus of mandible	307	51	91%	9%	$p < 0.001$	81%	19%	$p < 0.001$
Frontal section through facial skeleton at the level of the orbit	146	43	76%	24%	$p < 0.001$	79%	21%	$p < 0.001$
Lateral view of sagittal section through the orbit with contents	213	86	82%	18%	$p < 0.001$	76%	24%	$p < 0.001$
Cross-section through face at the level of the occlusal plane	167	47	91%	9%	$p < 0.001$	78%	22%	$p < 0.001$

The response rates (25% – nerve surgery, 9% – oral & maxillofacial surgery) were on average with respect to surgical societies and includes a risk of nonresponse bias as a limitation of the study.³¹⁻³³ However, the results allow for qualitative conclusions. First and foremost, among them is the fact that about half of surgeons (59% – nerve surgery, 49% – oral & maxillofacial surgery) are aware of the atlas, and 13% and 9% of the total population are currently using it for surgery. Of surgeons that are aware of the atlas, 77% and 64% respectively know about its historical Nazi origin. After presentation of the historical background of the atlas, most nerve surgeons (69%) were “comfortable” with the use of Pernkopf’s atlas in surgery, and a minority (15%) were “uncomfortable.” Less than half of oral & maxillofacial surgeons (45%) were “comfortable” and 33% were “uncomfortable” with the use of the atlas in surgery.

When surgeons were presented with four different ethical conditions that could be met in connection to the use of the atlas, a majority of those previously “undecided” or “uncomfortable” about its use changed their position and were now willing to employ the images in surgery (Fig. 5.1). While 65% of nerve surgeons and 61% of oral & maxillofacial surgeons would use Pernkopf’s atlas with the implementation of an ethical proposal, respectively, there were 29% and 13% who would use the atlas irrespective of these ethical conditions. The latter finding may derive from the unawareness of the still existing ethical controversy in using Pernkopf’s atlas in surgery,¹⁵ as a significant percentage of surgeons (6% and 19%) would not use the Pernkopf atlas under any condition. This percentage is even higher among nerve surgeons of Jewish descent (25%), however is the same (19%) in oral & maxillofacial surgeons. This may be explained by an older oral & maxillofacial surgeon demographic with 86% being in practice.

Any evaluation of using Nazi medical data, including the paintings of executed prisoners in Pernkopf’s atlas, needs to take account of the perspective of the victims, foremost amongst them Jews as the main target of Nazi persecution.^{29,30} There-

fore, the survey data from surgeons of Jewish descent were specifically examined. Twenty nerve surgeons and 48 oral & maxillofacial surgeons identified as of Jewish descent, and eight of them (1 – nerve, 7 – oral & maxillofacial) were currently using the Pernkopf atlas for surgical planning. After the presentation of the historical background of the atlas, there was substantial division of opinion in surgeons of Jewish descent, respectively, with 40% and 27% being comfortable and 45% and 46% being uncomfortable with respect to using Pernkopf's atlas in surgery. A larger percent (27%) of oral & maxillofacial surgeons compared to the 15% nerve surgeons were undecided. However, after presentation of the 4-point proposal of ethical conditions, surgeons of Jewish descent changed their opinion with fifteen (75%) nerve surgeons and thirty-nine (81%) oral & maxillofacial surgeons being comfortable and, respectively, five (25%) and nine (19%) remained uncomfortable in using Pernkopf's atlas in surgery. Importantly, 73% and 79% of surgeons of Jewish descent would like to see the implementation of the proposal compared to the 65% and 68% of all respondents. As the 4-point proposal can provide a roadmap towards the appropriate handling of Pernkopf's atlas, the second condition for achieving a consensus from bioethicists can only occur in part by proxy. Discussions within bioethics are continuously evolving and it is the individual's moral responsibility to recognize the outcomes of said discussions before employing the use of the atlas in surgery.¹⁵

There may exist a shift of opinion for using Pernkopf's atlas with the introduction of a new generation of nerve surgeons into the workforce. Remarkably, 82% of nerve surgery trainees would use the atlas in surgery and further adoption (100%) with the implementation of the 4-point proposal. However, there is reduced sentiment in the 23 oral & maxillofacial surgery trainees where nine (39%) felt originally comfortable with the use of the atlas, which improved to eighteen (78%) with the implementation of the 4-point proposal. These results aligns with most trainees finding value for using an advanced anatomical resource for learning surgery³⁴ and highlights the importance for discussing ethics in education when the Pernkopf atlas is used. This aligns with another study's finding that medical students would like to discuss Pernkopf's atlas within a bioethics course.²⁶

Currently, Pernkopf's atlas remains one of many choices among atlases and other anatomical resources used by surgeons (Table 5.4 and 5.5). In a comparison of selected images from Netter's atlas, the most often named atlas of use in this study (Table 5.5), both nerve surgeons and oral & maxillofacial surgeons see greater anatomical detail and surgical utility in Pernkopf's images (Table 5.6). An individual surgeon commented: "Netter's simplicity provides a great basis for surgery, however until seeing the complexity of peripheral nerves in Pernkopf's, I now understand the reason for its potential use," thus indicating the usefulness of Pernkopf's atlas in actual surgery, and Netter's atlas as a tool for anatomical orientation. This comment aligns with medical students identifying Netter's as a superior tool for learning compared to Pernkopf's.²⁶ As this study design prioritized the development of a 4-point proposal, the image comparison was performed at the end of the survey. Therefore, motivated cognition may play a role in these results for those that are historically aware of Pernkopf's atlas. Further comparison studies with other anatomical resources and atlases will explore the value of Pernkopf's atlas in anatomy

and surgery.

The results of these studies come at a time of renewed interest for transparency in tissue ethics. At a 2017 conference on the "Medical ethics in the 70 years since the Nuremberg Code" in Vienna, the question of whether to "use or not to use" data gained from coercive Nazi medical research to benefit the lives of patients was discussed.²⁷ Recommendations were formulated during a symposium at *Yad Vashem*, the Holocaust Martyrs Authority in Jerusalem, on "How to Deal with Holocaust Era Human Remains" and include the "Vienna Protocol" for when Jewish or possibly-Jewish remains are discovered.¹ In conjunction, we proposed 4 conditional points for the appropriate handling and continued use of Pernkopf's atlas in surgery and surgical education. This proposal was developed in response to *Yad Vashem's* request for a commemoration for the potential victims of Nazi terror and an acknowledgement documenting the history of Pernkopf in the atlas.²⁸

ETHICAL JUSTIFICATION

5

The unmatched quality and specialized utility of the medical information presented in the Pernkopf atlas counter the line of reasoning that has appropriately discredited the use of results generated by Nazi-era and/or Nazi-sympathizing, medical researchers.³⁵ However, ethical objections to using the Pernkopf atlas in patient care and medical education must be made on other grounds. There are many ways to frame and engage the significant ethical questions raised by the tragic and offensive origins of the atlas. Morality is concerned with the distinction between right and wrong that entails value judgments that are often traceable to societal norms or religious teaching and therefore may be abstract. On the other hand, law is very practical and sets the minimum requirements for behavior in a society. Ethics aims to capture the core values of a society by encouraging not just what must be done, but what should be done in specific situations.

The case study involving the use of Pernkopf's atlas in surgery represents an ethical dilemma faced by many surgeons who were trained with it, before or without awareness of its Nazi origins.³⁶ Yee and colleagues intentionally and strategically anchored this approach to ethics with real-time patient cases and thus framed the discussion as near as possible to how clinicians think – i.e. ethics involving the determination of what should be done, *all things considered*.³⁷ By definition, an ethical dilemma necessitates a choice between two compelling options. Once a decision is reached through a careful assessment of what should be prioritized and what weight should be given to each priority, the clinician's ethical responsibility shifts to implementing the decision in the least bruising way for the stakeholders whose interests are secondary to the prioritized objectives involving the patient. Nerve surgeons and oral and maxillofacial surgeons have determined disclosure and addressing the ethical implications as priorities across conditions generated through what could be done to provide some semblance of meaning to the lives lost in association with the atlas.³⁸

An action ideally is (1) inherently good and (2) leads to an optimal outcome, thus meeting the standard of both *deontological ethics* and *utilitarian ethics*.³⁹⁻⁴² In *deontological ethics*, an action is inherently good when the action, if generalized, would become an acceptable policy or law. Persons are never to be regarded as means, only as ends in themselves. In *utilitarian ethics*, the merit of an action is measured by its consequences. Individual freedoms may and should be sacrificed in the interest of the greater good. These two distinct and ethical approaches and mindsets may point to conflicting judgments regarding what ought to be done, as is evident in the question regarding whether or not to use the Pernkopf atlas. Given the potential for better surgical outcomes, a strictly pragmatic utilitarian evaluation would conclude “yes, absolutely.” However, in line with avoiding ever using a person as a means to an end, a deontological categorical response would argue “no, definitely not.” This deeply rooted tension – i.e. the urge to use all available resources for the best possible outcome or the need to respect victims who were tragically exploited – cannot be ignored or slighted.

A separate and *third approach* is proposed here to justify the use of the Pernkopf atlas that could be the most ethically compelling and responsible – i.e. a “lesser of two evils” approach. This approach suggests surgeons who use the atlas to benefit patients bear considerable “ethical dissonance,” but not to the threshold of clinically disabling them or putting patients at risk. For these surgeons, the analytical tool of “double effect” may be useful. The *double effect* reasoning proposes that an action with two or more possible effects – one beneficial and the other(s) not beneficial – is ethically justified if the action is (1) not in itself unethical, (2) undertaken with the intention to achieve the possible and beneficial outcome desired by the patient without intending other foreseen and undesired outcome(s), and (3) undertaken for a proportionately and compellingly grave reason.⁴³

Surgical specialties differ dramatically – while some surgeons do not need to consult an atlas due to routine operations and manipulating well-known anatomical planes and tissues broadly, nerve and oral and maxillofacial surgeries can require intricate maneuvers of complex neurovascular anatomy to recover function such as composite tissue allotransplantation and facial reanimation procedures. For surgeons who are prepared – *all things considered* – to use the Pernkopf atlas under specific circumstances, their obligation to maximize patients’ self-determination requires that they disclose sufficient information about the controversial origins of the atlas for a patient (and family) to consider this information in giving informed consent for a surgery that includes the atlas’s use. The commitment to self-determination also extends this need for disclosure to colleagues and trainees when surgeons use the atlas for educating the operative team.

Questions regarding the use of the Pernkopf atlas have previously focused on a narrowly defined set of nerve surgeries.^{36,38,44} The atlas continues to be uniquely informative for illuminating the underlying anatomy for these surgeries and guiding the resolution when faced with anatomically complex problems. An argument can be made that the atlas’s use in complex nerve surgeries provides additional surgical options to patients, which shapes the meaning/extent of the “benefit” associated

with these surgeries. Ethical considerations that include the 4-step graduated protocol are recommended when using the atlas in a manner that optimizes patient benefit, respects patient self-determination, and honors the deceased victims of Nazi ideology whose remains were used in the creation of the atlas.³⁶ Future work is required to confirm the feasibility of this protocol and whether patients do benefit from the educational use of the atlas. These potential studies may enhance the necessary discussions among the stakeholders, including those who are surrogates for the victims of Nazi atrocities.

An objective of this assessment was to determine whether oral and maxillofacial surgeons found the Pernkopf atlas similarly unique as an educational and clinical resource to nerve surgeons, where the portrayal of complex nerve anatomy is critical for function. If not, then the priority and weight, given the considerations to use the atlas, is marginal for oral and maxillofacial surgeons and not ethically compelling. However, oral and maxillofacial surgeons require extensive knowledge of the complex anatomy of the head and neck. Therefore, it is not surprising that the initial assessment of oral and maxillofacial surgeons mirrored nerve surgeons,³⁸ and thus the priority and weight should be similarly pivotal in the ethical reasoning upon which the decision to use the atlas is based.

5

CONCLUSION

Nerve surgeons and oral & maxillofacial surgeons continue to use Pernkopf's atlas to inform surgical planning. The 4-point ethical proposal outlined here can be used as guidance for its ethical handling, including a provision to memorialize the victims of the horrendous atrocities committed by the Nazi regime. The Pernkopf controversy continues to divide opinions in the world of surgery and elsewhere, which highlights the importance to communicate the atlas's historical origin and the associated ethical challenges for use in surgery.

REFERENCES

1. Polak JA. "Vienna Protocol" for when Jewish or Possibly-Jewish Human Remains are Discovered. In: Seidelman WE, Elbaum L, Hildebrandt S, eds. *How to Deal with Holocaust Era Human Remains: Recommendations arising from a special symposium*. Boston, MA: Elie Wiesel Center for Jewish Studies, Boston University; 2017.
2. Israel HA, Seidelman WE. Nazi origins of an anatomy text: the Pernkopf atlas. *JAMA*. 1996;276(20):1633; author reply 1634.
3. Pernkopf E. *Atlas of Topographical and Applied Human Anatomy. Volume 1: Head and Neck. Volume 2: Thorax, Abdomen and Extremities*. Philadelphia and London: W.B. Saunders Co.; 1963.
4. Akademischer Senat der Universität Wien. Senatsprojekt der Universität Wien: Untersuchungen zur Anatomischen Wissenschaft in Wien 1938–1945. (Unpublished Manuscript). In: Akademischer Senat der Universität Wien.; 1998.
5. Angetter DC. Anatomical science at University of Vienna 1938–45. Senate Project of the University of Vienna. *Lancet*. 2000;355(9213):1454–1457.
6. Malina P, Spann G. Das Senatsprojekt der Universität Wien "Untersuchungen zur Anatomischen Wissenschaft in Wien 1938–1945". *Wien Klin Wochenschr*. 1999;111(743–53).
7. Weissmann G. Springtime for Pernkopf. *Hosp Pract (Off Ed)*. 1985;20(10):142–168.
8. Williams DJ. The work of Eduard Pernkopf, et al. 37th Annual Meeting of the Association of Medical Illustrators; 1982/10/13, 1982; Anaheim, CA.
9. Williams DJ. The history of Eduard Pernkopf's Topographische Anatomie des Menschen. *J Biocommun*. 1988;15(2):2–12.
10. Pernkopf E. Topographische Anatomie des Menschen. In: *I. Band: Allgemeines, Brust und Brustgliedmasse*. Berlin: Urban und Schwarzenberg; 1943:7.
11. Atlas MC. Ethics and access to teaching materials in the medical library. *Med Law*. 2000;19(3):463–473.
12. Atlas MC. Ethics and access to teaching materials in the medical library: the case of the Pernkopf atlas. *Bull Med Libr Assoc*. 2001;89(1):51–58.
13. Hubbard C. Eduard Pernkopf's atlas of topographical and applied human anatomy: the continuing ethical controversy. *Anat Rec*. 2001;265(5):207–211.
14. Hildebrandt S. How the Pernkopf controversy facilitated a historical and ethical analysis of the anatomical sciences in Austria and Germany: a recommendation for the continued use of the Pernkopf atlas. *Clin Anat*. 2006;19(2):91–100.
15. Yee A, Zubovic E, Yu J, et al. Ethical Considerations in the Use of Pernkopf's Atlas of Anatomy: A Surgical Case Study (In Preparation). *Surgery*. 2018.
16. Muehlberger K. Enthebungen an der medizinischen. Fakultät 1938–1945. *Wien Klin Wochenschr*. 1998b;110:115–120.
17. Hildebrandt S. *The Anatomy of Murder: Ethical Transgressions and Anatomical Science during the Third Reich*. New York: Berghahn Books; 2016.
18. Morris H. *Morris' Human Anatomy: A Complete Systematic Treatise*. 11th ed. New York, NY: The Blakiston Co.; 1953.
19. Drake R, Vogl AW, M. MAW, Tibbitts R, Richardson P. *Gray's Atlas of Anatomy*. 2nd ed: Churchill Livingstone; 2014.
20. Netter FH. *Atlas of Human Anatomy*. 6th ed: W. B. Saunders; 2014.
21. Agur AMR, Dalley AF. *Grant's Atlas of Anatomy*. 13th ed: Lippincott Williams & Wilkins; 2012.
22. Gilroy AM, Macpherson BR, Ross LM, Schuenke M, Schulte E, Schumacher U. *Atlas of Anatomy*. 2nd ed: Thieme; 2012.
23. Tank PW, Gest TR. *Lippincott Williams & Wilkins Atlas of Anatomy*. 1st ed: Lippincott Williams & Wilkins; 2008.
24. Rohen JW, Lütjen-Drecoll E, Yokochi C. *Color Atlas of Anatomy: A Photographic Study of the Human Body*. 7th ed: Lippincott Williams & Wilkins; 2010.
25. Paulsen F, Waschke J. *Sobotta Atlas of Human Anatomy*. 15th ed: Urban & Fischer; 2013.
26. Coombs DM, Peitzman SJ. Medical Students' Assessment of Eduard Pernkopf's Atlas: Topographical Anatomy of Man. *Ann Anat*. 2017;212:11–16.
27. Hildebrandt S, Seidelman WE. Where do they come from? A call for complete transparency regarding the origin of human tissues in research. *ESMO Open*. 2017;2(2):e000201.

28. Cutler DS. Origins of the Pernkopf anatomy atlas. *JAMA*. 1997;277(14):1122; author reply 1123-1124.
29. Ball P. Naming the victims of Nazi medicine. *Lancet*. 2017;389(10085):2182-2183.
30. Matuchansky C. Naming of the victims of Nazi medicine. *Lancet*. 2017;390(10098):933.
31. Reinisch JF, Yu DC, Li WY. Getting a Valid Survey Response From 662 Plastic Surgeons in the 21st Century. *Ann Plast Surg*. 2016;76(1):3-5.
32. Wasterlain AS, Melamed E, Bello R, Karia R, Capo JT, Science of Variation G. The Effect of Price on Surgeons' Choice of Implants: A Randomized Controlled Survey. *J Hand Surg Am*. 2017;42(8):593-601 e596.
33. McMahon SR, Iwamoto M, Massoudi MS, et al. Comparison of e-mail, fax, and postal surveys of pediatricians. *Pediatrics*. 2003;111(4 Pt 1):e299-303.
34. Mundschenk MB, Odom EB, Ghosh TD, et al. Are Residents Prepared for Surgical Cases? Implications in Patient Safety and Education. *J Surg Educ*. 2017.
35. Caplan AL. *When Medicine Went Mad: Bioethics and the Holocaust*. New York NY: Springer Science & Business Media; 2012.
36. Yee A, Zubovic E, Yu J, et al. Ethical considerations in the use of Pernkopf's Atlas of Anatomy: A surgical case study. *Surgery*. 2018;165(5):860-867.
37. Brown D. Surgical Ethics: Theory and Practice Background. In: Ferreres AR, ed. *Surgical Ethics: Principles and Practice*. Switzerland: Springer; 2019.
38. Yee A, Coombs DM, Hildebrandt S, Seidelman WE, Coert JH, Mackinnon SE. Nerve Surgeons' Assessment of the Role of Eduard Pernkopf's Atlas of Topographic and Applied Human Anatomy in Surgical Practice. *Neurosurgery*. 2018;84(2):491-498.
39. Beauchamp T, Childress J. *Principles of Biomedical Ethics*. 6th ed. New York: Oxford University Press; 2009.
40. Taylor S. Health Care Ethics. Internet Encyclopedia of Philosophy (IEP) Web site. <https://www.iep.utm.edu/21>. Published 2020. Accessed May 15, 2020.
41. Conway P, Gawronski B. Deontological and Utilitarian Inclinations in Moral Decision Making: A Process Dissociation Approach. *J Pers Soc Psychol*. 2013;104(2):216-235.
42. Gawronski B, Beer J. What Makes Moral Dilemma Judgments 'Utilitarian' or 'Deontological'? *Soc Neurosci*. 2017;12(6):626-632.
43. Sulmasy D, Pellegrino E. The Rule of Double Effect: Clearing Up the Double Talk. *Arch Intern Med*. 1999;159(6):545-550.
44. Mackinnon S. When medical information comes from Nazi atrocities. *BMJ*. 2020;368:l7075.

CHAPTER 6

ETHICAL CONSIDERATIONS IN THE USE OF PERNKOPF'S ATLAS OF ANATOMY

A SURGICAL CASE STUDY

Based on:

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Caplan AL. Commentary: Consulting evil. *Surgery*. 2019;165(5):870.

Müller M, Czech H, Druml C. Commentary: The Medical University of Vienna and the historic legacy of Pernkopf's atlas. *Surgery*. 2019;165(5):871-72.

ABSTRACT

The use of Eduard Pernkopf's anatomical atlas presents ethical challenges for modern surgery concerning the use of data resulting from abusive scientific work. In the 1980s and 1990s, historical investigations revealed that Pernkopf was an active National Socialist (Nazi) functionary at the University of Vienna, and that among the bodies depicted in the atlas were those of Nazi victims. Since then, discussions persist concerning the ethicality of the continued use of the atlas, as some surgeons still rely on information from this anatomical resource for procedural planning. However, the ethical implications relevant to the use of the atlas in surgical patient care have not been discussed in detail. Based on a recapitulation of the main arguments from the historic controversy surrounding the use of Pernkopf's atlas, this study presents an actual patient case to illustrate some of the ethical considerations relevant to the decision of whether to use the atlas in surgery. This investigation aims to provide a historical and ethical framework for questions concerning the use of the Pernkopf atlas in the management of anatomically complex and difficult surgical cases, with special attention to implications for medical ethics drawn from Jewish law.

INTRODUCTION

The history of anatomy is one of scientific knowledge gained at the “edge of the cultures,” sometimes transgressing this edge into the territory of crime and atrocities.^{1,2} Despite this history, the ethical justification for using anatomical knowledge gained from the bodies of victims of atrocities has not been questioned, with one exception: the Pernkopf atlas. Eduard Pernkopf's *Topographische Anatomie des Menschen* (*Topographical Anatomy of Man*) was received as a well-regarded atlas featuring high-quality paintings; the first ever to use the four-color offset printing technique.³ Eventually published in five languages, the atlas was widely used by anatomists and surgeons around the world until the 1990s. At that time, an ethical controversy arose when the work's origin in the context of the abusive political system of National Socialist (Nazi) Germany was revealed.⁴⁻⁹ A historical investigation at the University of Vienna documented that many of the images in the atlas might be derived from executed victims of the Nazi regime. An ethical debate ensued which revolved around the use of such images.¹⁰⁻¹⁶ Despite restrictions in accessing the book by some libraries, and the decision of the publisher to stop reprints, the atlas continued to circulate in the used book market and on the internet without disclosure of its history. It is assumed that thousands of copies remain in private collections. Individual surgeons continue to use the images because of their illustrative accuracy and quality.¹⁷ Indeed, some users of the atlas believe that this visual information potentially benefits patients by informing complex surgical planning. However, so far there exists no detailed ethical discussion of the potential benefit or harm for the patient in association with the use of the atlas. To illustrate the various ethical considerations relevant to the decision of whether to use the atlas in surgery, the following study presents a real patient case study and then recapitulates the main arguments from the historic controversy surrounding the use of Pernkopf's atlas. The aim is to provide a historical and ethical framework for questions concerning justifications for the use of the Pernkopf atlas in the management of anatomically complex and difficult surgical cases.

6

As the Pernkopf atlas was created under the degrading conditions of the Nazi regime, special consideration will be given to the implications for medical ethics drawn from Jewish law. While many victims of the Nazi atrocities were non-Jews, the persecution of Jews in the Holocaust was a specific focus of Nazi genocide that is unique among the many other genocides the world experienced then and, unfortunately, continues to experience.¹⁸ There is no example of ethical guidelines on the use of data or images from these victims that include the *voice of victims*. In the specific context of Nazi Germany and the Holocaust, it is important to consider the voice of the principle group of victims, the Jews. This voice is expressed in a new responsum by Rabbi Joseph Polak in the “Vienna Protocol,”¹⁹ so named because of the Vienna origins of the atlas. The Pernkopf atlas and the guidelines of the “Vienna Protocol” are discussed here as having ethical relevance that goes beyond the Jewish context and may be applicable in many other religious and secular settings, thus addressing all humanity.

A CASE STUDY IN THE OPERATING ROOM

A 50-year-old female presents to a peripheral nerve surgeon with the chief complaint of debilitating neuropathic pain on the medial aspect of the right knee and a complex history of knee replacements. She reports that her neuropathic pain began immediately after a partial knee replacement, and significantly worsened after subsequent surgical attempts of revision. At presentation, the patient reports 9/10 pain, 9/10 negative impact on her quality of life, and 6/10 depression. She has exhausted multiple strategies for pain management, and has stated that she would consider a leg amputation if the pain could not be resolved in any other fashion.

The surgeon makes a clinical diagnosis of saphenous nerve entrapment in the mid-thigh, and neuroma pain in the infrapatellar branch of the saphenous nerve. A corresponding Tinel's sign along the course of the infrapatellar branch, and a positive clinical provocative test at the entrapment point can be elicited. The patient also responds to a saphenous nerve block at the entrapment point.²⁰ The patient is informed on the nature of the procedure and voluntarily consents to the decompression of the saphenous nerve in the thigh, and excision of the involved neuromas with proximal transposition of the saphenous nerve for management of the neuropathic pain.

This surgeon has a reputation for being a leading expert in nerve surgery. Despite the 30-year surgical experience, the surgeon's frequency for a saphenous nerve release surgery was limited at the time of presentation. Due to the relative rarity of the procedure, the surgeon encounters intraoperative difficulty and frustration at not being able to locate and identify the saphenous nerve within the entrapment point, which is deep to the anteromedial (vastus-adductor) intermuscular septum, and the distal infrapatellar branch. The surgeon proceeds to take an intraoperative time out to determine how to proceed.

It is at this very specific moment, when the surgeon encounters an ethical dilemma in considering the use of Pernkopf's atlas to inform surgical planning. As a historical note, the surgeon received Pernkopf's atlas as a gift in 1982 when first beginning to practice. This atlas became an important anatomical reference for surgery due to its detail and accuracy for the peripheral nervous system. It was not until several years later in the mid-1980s, that the surgeon first became aware of the controversy behind the origin of the book.⁶

HISTORY OF PERNKOPF'S ATLAS

Over the past three decades, inquiries have been made regarding Eduard Pernkopf's and his illustrators' political background, and about the origins of the human bodies depicted. In the 1980s, the historically interested physician Gerald Weismann revealed Pernkopf as a member of the Nazi Party (NSDAP),⁶ and the medical illustrator David J. Williams researched more than 800 original paintings from the atlas. During interviews with Franz Batke, the last surviving artist contributing to the

atlas, Williams found that all illustrators of the atlas had Nazi sympathies or were members of the NSDAP.⁸ Signs of this allegiance were clearly visible in several of the anatomical plates, with painter Erich Lepier adding Swastikas to his signature (airbrushed out in later editions of the atlas), illustrator Karl Endtresser signing his double "SS" in the shape of lightning-bolt SS (*Schutzstaffel*) symbols, and Batke shaping the 44 in the date 1944 as the SS runes (Fig. 6.1). Williams addressed Pernkopf's atlas as a "troubled masterpiece." Inquiries continued in 1995, when the Professor of Complementary Medicine Edzard Ernst published a report in the *Annals of Internal Medicine* about Pernkopf's personal involvement in the removal of all faculty members who were of Jewish origin or political opponents in his role as Dean of the Vienna Medical School.²¹ It was revealed that a majority of the medical faculty were dismissed, of whom most emigrated, some committed suicide, and others were deported to concentration camps and death.²²

FIGURE 6.1. Signatures of Pernkopf's illustrators demonstrating Nazi sympathies. (Upper line) Normal signatures without signs of Nazi sympathies. (Middle line) Signatures with swastika and lightning-bolt SS (*Schutzstaffel*) symbols. (Lower line) Lepier's signature was airbrushed to remove the appearance of the swastika in the second and third editions of the atlas. Remnants of the swastika can be still be seen in some of his signatures. Endtresser's and Batke's lightning-bolts remained unchanged.

In 1997, the former publisher Urban & Schwarzenberg acknowledged Pernkopf's NSDAP membership, but argued that there was no concrete evidence for the use of bodies from Nazi concentration camp victims for the creation of the atlas.²³ However, following persistent inquiries by New York oral surgeon Howard Israel and Canadian physician William Seidelman, *Yad Vashem* (Israel Holocaust and Martyrs Remembrance Authority) had sent an official letter to the Austrian authorities and the University of Vienna, asking for an investigation into the origin of the atlas.^{12,13,24} In that same year 1997, the University of Vienna ultimately responded by admitting to a systematic suppression and denial of the anatomy department's Nazi past,²⁵ and therefore created a historical research commission, the "Senatorial Project of the University of Vienna."⁹ The objectives of the "Senatorial Project" were to (1) investigate the origin and destiny of the bodies used by Pernkopf, and (2) determine the extent of his Nazi affiliations and political activities.⁵

The Senatorial Project ascertained that during the Austrian Nazi period from 1938 to 1945, the Vienna Anatomical Institute received (1) 3,964 unclaimed bodies from hospitals and geriatric institutions, (2) 7 willed body donations, (3) about 7,000 bodies of fetuses, stillborn babies and children, all dead from natural causes, and including 4 Jewish children, and (4) at least 1,377 bodies of executed persons guillotined

at the Vienna assize court following court trials or shot by the Gestapo at a rifle range, including eight of Jewish origin.

There was no evidence that bodies from the two concentration camps close to Vienna, Mauthausen and the affiliated camp Gusen, were brought to the anatomical institute, but such bodies were transported to the anatomical department at the University of Graz.^{4,5} It should be noted that the anatomical use of unclaimed bodies from public institutions, including those of prisoners, children and fetal remains, was traditional and legal at the time, and even included the bodies of executed persons. However, the quantity of bodies of executed prisoners and the reasons for executions had changed dramatically under the Nazi regime. More than half of the executions in Vienna had been carried out for political reasons, among them 526 verdicts of “high treason”, which included offenses ranging from active political opposition to minor crimes. Of the eight Jewish victims, one was claimed by the family after the anatomical institute waived its own claim to the body because of transportation difficulties in 1939, and the other seven were delivered to the anatomical institute between 1942 and 1944.²⁶ The investigation also revealed anatomical specimens suspected to have originated from Nazi victims in various medical collections, which were then removed, and on March 22, 2002 were interred in an *Ehrengrab* (commemorative “grave of honor”) provided by the city of Vienna.^{4,5} It was ascertained that of the 791 illustrations in the atlas, about half had been created either before 1938 or after 1945. Forty-one plates were definitively based on bodies from the group of 1,377 executed victims. For the remaining approximately 350 paintings created between 1938 and 1945, the origin of the bodies used as models remained unclear.⁴ The Senatorial Project did not consider the illustrations produced after the war as potentially based on bodies of executed Nazi victims; however, the Vienna Anatomical Institute retained a considerable number of these bodies for several years after 1945.²⁷

The findings from the Senatorial Project sparked an ethical controversy surrounding the handling of Pernkopf’s atlas.^{9,16,28} Most medical libraries decided to retain and move the volumes into their special collections with the insertion of a historical note.^{10,11} While the former publisher Urban & Schwarzenberg ceased publication of Pernkopf’s atlas in 1994,^{28,29} the atlas continued to exist in the used book market and on the internet without disclosure. However, the question of using images from the “tainted” work in surgical patient care remains an ethical dilemma and was part of a discussion during a 2017 conference on the “Medical ethics in the 70 years since the Nuremberg Code.”^{30,31} Experts considered the question of whether or not to use data gained from coercive medical research in Nazi Germany, and in this context, discussed the use of information from anatomical research on the bodies of thousands of victims of the Nazi regime.

THE ETHICAL DILEMMA

The ethical question is, whether a surgeon cognizant of the historical background of the Pernkopf atlas may use its images in patient care. Indeed, the atlas represents

an example of Nazi medical scientists producing scientifically significant anatomical work, and in various surgical specialties, surgeons have found value in using this atlas in the operating room to benefit patient care.¹⁷ Whereas some of the more notorious medical experiments performed by Nazi scientists were scientifically flawed and produced false data, others followed the scientific method, though under unethical conditions, and produced relevant results.³²⁻³⁹ Also, scientific medical work in Nazi Germany was, if not always innovative,⁴⁰ and contrary to claims by postwar scientists and physicians,⁴¹ to a certain extent similar to that performed in other political systems at the time, and became part of the general canon of medical knowledge.^{36,37} It is essential to examine the atlas within this historical context, as Pernkopf operated under the specific conditions of the time, among them changes in the anatomical procurement that included an increasing number of bodies from victims of the Nazi government.⁴⁰ He and other anatomists contributed significant anatomical publications that were based on tissues from executed victims,⁴²⁻⁴⁴ whereas by now, body procurement has changed and unclaimed bodies in anatomy have been replaced with willed donor programs in most of Europe and the USA. Meanwhile, the papers and books based on data from the Nazi victims continue to exist within the body of scientific and anatomical knowledge. Any new ethical evaluation of the use of Nazi medical data needs to account for the perspective of those most affected, the victims who were used in the experiments and rarely have had a chance to participate in this discussion. Once forcibly subjected to medical experimentation, their voices cannot again be neglected in the debate over the use of data from these experiments.^{45,46}

JEWISH ETHICS AND LAW

BY RABBI JOSEPH A. POLAK

With respect to victims of medical crimes, despite the revelations of the Nuremberg Medical Trial, there was very little consideration of the role of medicine in the crimes of the Third Reich. The "Great Silence" that extended for decades was a consequence of suppression and repression by academic leaders in universities, leading scientific institutions, and professional organizations. Pursuit of research in this subject was not career enhancing. In the late 1980s, credible documentation began to emerge along with a growing body of research into the significant role played by medicine and medical science in the crimes of the Third Reich. Revelations included the discovery of the remains of victims of Nazi terror exploited by university institutes of anatomy and research institutes that had been part of the prestigious Kaiser-Wilhelm research organization, now known as the Max Planck Society. With these discoveries during a more accepting academic and political climate, significant ethical questions began to be asked. The Jewish ethical perspective is now emerging as an important consideration in an examination of these issues. As Jews stood at the center of Nazi persecution, destruction and genocide, it is imperative to include the analysis of Jewish bioethics and law in the discussion.^{45,46}

Several distinctions are made in Jewish law and ethics when addressing the permissibility of using the dead human body in education, research, and therapy. There is

decreasing concern and growing acceptability as one moves from use of the whole body to body parts (organ tissue, bone), biopsies, histology slides to photos and drawings. There is also a distinction in the justification for the use of human bodies for forensic reasons and the determination of the cause of death, pathological confirmation of the diagnosis, and documentation of quality of care. There are differences between research and use of the dead human body as a resource for therapy such as stem cells, tissues, and transplantation. Finally, there are questions about the use of dead human bodies for medical and anatomical education.

All Jewish ethics and law ultimately comes from the written and oral Torah. All *Halakha* (Jewish law) starts with the sanctification of human life. In the Jewish religious tradition, the human being is created in G-d's image, thus the individual human being does not have ownership over his or her body. All medical ethics around the living and the dead, in the Jewish tradition, is subsumed under three grounding principles:

1. The sacredness of life. This includes human life; it includes animal life (e.g. a newborn calf may not be slaughtered on the same day as its dam), and vegetable life (concepts of sacred crops, sabbatical years, and not mixing diverse seeds).
2. Divine rather than human ownership and proprietorship of the human body.
3. The human body, even after death, retains its identity as a sacred symbol of the divine and of what is sacred about the human, and in this double-symbolism, may never be desecrated.

Deriving benefit from a corpse is part of the broader halakhic category of *Nivul haMet* (the prohibition of physical desecration of the body). Early discussion of problems with the use of a dead human body appeared around the 17th century, raising the question whether the study of a corpse constitutes "benefit" from the deceased, which in itself is a prohibited activity in Talmudic law. A second prohibited category is *Halanat ha'Met* (leaving the dead unburied overnight). Halakha requires a quick and speedy *K'vura* (burial). Any delay constitutes a violation of *Kavod haMet* (respect for the dead). An overriding principle of Jewish Law is *Pikuach Nefesh* (saving a life). Normally, all halakhic considerations are suspended for *Pikuach Nefesh*. The three exceptions are: murder, incest/adultery, and idolatry.

The Pernkopf atlas, the subject of this discussion, does not display the actual body, organs, or tissues of its subject, nor even photographs of it. It does contain paintings. This removes the halakhic emphasis away from the object of the atlas (corpses, tissues, etc.) to the representation of such body parts. The question now becomes: if someone in their will says "you may copy my body parts for science after I die but before I am buried." Is this halakhically permitted? The answer here would be no because the body, as we have seen, is not the property of the person who inhabited it.

Enter the Pernkopf atlas. The body, in fact, does not lie before us; only the paintings remain. Do the prohibitions of benefit, of no post-mortem overnight, and of representation extend to what is already here; and does the fact that these paintings were of victims of murder enter the moral argument?

We have argued elsewhere in the "Vienna Protocol" that they do,¹⁹ but the fact that these are representational rather than real, support limited permissibility when *Pikuach Nefesh* (as in surgery, and possibly medical education) is at play. Then the tertiary level of the paintings (from corpse to photograph to drawing) comes into play. Those halakhic authorities who condone studying anatomical remains under normal (i.e. normally expired corpses) circumstances would also permit the study and use of pictures in the Pernkopf atlas. However, they would likely be reluctant to do so, it should be argued, unless the paintings carry an elaborate warning label describing the provenance of their subjects, and articulated an understanding of the controversy around the criminal acquisition of the corpses on which the drawings are based.

All, would agree that should the atlas be used, it should indeed be used with respect and gratitude, and with appropriate solemnity. Moreover, if it is certain that if one can save a life using this atlas, then doing so would not only be permissible, but probably mandatory.⁴⁷

DISCUSSION

In recognition of the fact that Pernkopf's atlas presents an ethical dilemma to its users due to the complex historical and potential religious implications outlined above, decisions on how to deal with this image resource will depend on the moral values of the individual user. Based on the principle of honoring and respecting the lives of those past, present, and future, the following discussion examines four of possibly many ways to proceed:

- Option 1: Continue with the case and recognize a time to stop the procedure.
- Option 2: Call a surgical colleague for emergency consultation in the operating room.
- Option 3: Take an operative time out and consult an anatomy atlas other than Pernkopf.
- Option 4: Take an operative time out and consult Pernkopf's Atlas of Human Anatomy.

OPTION 1

Continue with the case and recognize a time to stop the procedure.

The intraoperative decision to stop a procedure (operative time out) at critical moments is a hallmark of expert performance.⁴⁸ Stopping surgical progression is an extreme manifestation of slowing down, where the surgeon recognizes the moment to acquire additional information before making a judgment. The surgeon may review the patient's file and imaging, ask a colleague for assistance, and/or consult anatomical resources. Operative time outs are known to help reduce medical errors by recapping surgical progression, minimizing distractions, and proactively analyzing possible paths forward.⁴⁹ The decision to terminate a procedure typically comes

when the surgeon has exhausted all other resources and recognized the limit of their own abilities to avoid doing harm to the patient, their first ethical obligation.

Despite having adequate surgical training to appropriately handle unplanned challenges in the operating room, rare or unusual cases do occur and present an increased risk for potential complications. This was a driving force for the development of progressive specialization within surgery. Specialists have the experience required to handle difficult, complex, and rare cases, for which they are considered “end-of-the-road” expert surgeons. Despite an increased volume of complex and rare cases, these surgeons can also encounter unplanned challenges, occasionally requiring an operative time out. During these moments, the surgeon can assess options, and either proceed with surgery or terminate the procedure if the risks of proceeding outweigh any potential benefit to the patient.

In the scenario presented, the surgeon undertook a rare case referred by another surgeon, who was unsuccessful in managing the patient’s neuropathic pain. During the case, the surgeon encountered difficulty in obtaining adequate exposure of the saphenous nerve, and an operative time out was taken to reassess and consider other options. In this situation, the surgeon must rely on his or her acquired knowledge and experience to judge what is best for the patient. If the surgeon sees no safe way to continue the operation, the decision to abort the case can be made.

OPTION 2

Call a surgical colleague for emergency consultation in the operating room.

Seeking the opinion of a colleague may provide the surgeon with a new perspective on the situation and additional insight into how to proceed with the operation.⁵⁰ Encountering intraoperative surgical difficulty and frustration can contribute to a higher mental workload, which has been associated with intraoperative complications during laparoscopic procedures.⁵¹ The recognition of a stopping point to reassess and request assistance from a surgical colleague is a trait of expert performance.⁴⁸ The surgical colleague can provide another perspective and a “fresh set of eyes” for resolving the situation. A difference in surgical experience can contribute an alternative strategy or additional technical expertise. Furthermore, a second or senior opinion can also provide the appropriate rationale for aborting the case, if other options are exhausted.

The ability to call for an emergency consultation with a specialist surgeon is a benefit often found at larger or academic centers. However, if a complex case was referred to an “end-of-the-road” surgeon, an emergency consultation may not provide a more experienced surgeon’s opinion but rather a different perspective. In the scenario presented, the case was referred to an “end-of-the-road” expert surgeon at a large academic center. While this surgeon could consult a surgical colleague, it is known that these consultations would not provide expertise on approaching the saphenous nerve. This is due to the expert’s level of experience for treating complex nerve cases compared to their surgical colleagues. While asking for surgical

assistance is one option for navigating surgical difficulty, this can be of limited value in cases where no other more experienced surgeon is available. Consulting other resources such as technical articles and/or anatomical atlases can be considered.

OPTION 3

Take an operative time out and consult an anatomy atlas other than Pernkopf's atlas.

It is said that the mark of a good resident is knowing when to ask for help; why should this not hold true for a practicing physician, especially when faced with a rare or unusual problem? It is common practice to request the assistance of a more experienced colleague or consult another specialty surgeon intraoperatively when presented with an unexpected problem. It is, however, a rare occurrence in most operating rooms for a surgeon to reference an anatomical atlas. When there is no more experienced colleague available, and the dilemma lies in navigating a difficult or rarely seen dissection, which will present itself to even the most specialized surgeon, reference to an anatomical illustration may provide the necessary guidance. The surgeon can use the images of standard human anatomy to compare to the intraoperative anatomy, and to assist in landmark identification for a safe and successful dissection of the nerve or structure in question.

Using radiology in the same way is commonplace and not considered a crutch. A general surgeon may have computed tomographic images projected on a monitor to identify a tumor's relationship to key structures, or an orthopedic surgeon may reference plain radiographs in approaching a fracture. For procedures involving anatomy not easily seen on imaging such as peripheral nerves, especially those addressed surgically only in rare instances, there is no equally reliable imaging technique to guide the surgeon through a difficult dissection. An anatomy atlas may be an essential reference to have available in the operating room.

The surgeon may choose to reference a variety of anatomy texts. Most physicians were educated on an atlas other than Pernkopf, and the atlases in common circulation – Netter's, Gray's, Grant's, Sobotta's and others – are adequate for general anatomy reference. They are, however, arguably much less detailed than the Pernkopf illustrations (Fig. 6.2).^{17,52} Specifically, the Pernkopf atlas gives much more elaborate visual information in terms of the topography of peripheral nerves than any other of the anatomical atlases.¹⁷ The surgeon can choose to reference a non-Pernkopf atlas for one of two reasons – for lack of availability of the Pernkopf atlas, or for ethical opposition to its use. But in a case that poses a challenging dissection for a highly-specialized surgeon, the question remains whether one of these standard atlases is sufficient.

OPTION 4

Take an operative time out and consult Pernkopf's Atlas of Human Anatomy.

The choice to consult Pernkopf's controversial atlas as an anatomical resource during surgery should not be taken lightly, indeed only under the conditions outlined above. The fact that Pernkopf's atlas has become an integral part of some surgical practices signifies a gap in the anatomical and illustrative sciences and a need to develop a better anatomical resource that may put the apparent need to use the Pernkopf atlas to rest. However until that exists, the following discussion summarizes some of the ethical implications in the use of Pernkopf's atlas in complex or rare surgical cases.

The use of Pernkopf's atlas for treating patients to the best of one's ability should be an autonomous decision and should serve the principle of helping – and not harming – the patient.⁵³ This is where the ethical dilemma exists. Does one help the patient using a resource derived from potentially unethical practices if it could help the surgeon proceed with the case, or is the patient potentially harmed by his or her indirect association with a "tainted" resource? Does one make use of alternative resources knowing that these may perhaps not resolve the issue at hand? The surgeon may not be able to consult with others for another opinion. The strict conditions laid out in the "Vienna Protocol" (saving human life, historically informed use, commemoration and honoring of the victims) provide an ethical option for the use of certain Pernkopf images in a manner that memorializes the potential Nazi victims,¹⁹ while at the same time benefitting today's patients. It is exactly these strict conditions and limitations that transcend the impact of the "Vienna Protocol" beyond the world of Jewish law into all contexts of modern medicine. At the center are self-restraint of the physician's choice, historical insight, and recognition of the humanity of the subjects in the images as well as of the patient to be treated.

While many surgeons are now informed on the history of Pernkopf's atlas, this was not always so. For highly specialized surgeons, especially head, neck, and extremity surgeons, the atlas became integrated into their practice prior to the exposure of its history. It became a significant resource as they developed their practices and the atlas gained a reputation for its anatomical accuracy. These surgeons see their work with the atlas as evolving with their practice, and report attaining new anatomical insight with experience. They have "learned to see," as formerly overlooked anatomical details can become more apparent with increased surgical expertise and critical observation: "It was always there, I never saw it." For some surgeons, Pernkopf's atlas arguably represents a pinnacle of anatomical illustration. However, now surgeons are ethically obligated to decide whether to continue using this resource. These specialized surgeons live in moral dissonance with knowledge of the atlas' tragic past, and they are required to make a judgment call in the operating room.

In the described case study, the surgeon returned to the operating room and chose to use Pernkopf's atlas, knowing that there was no other available image to aid progress through a difficult operative period. An image from this atlas was for this surgeon, the only anatomical drawing available to navigate the complex anatomy

FIGURE 6.2. Relevant anatomical and illustrative plate comparison. (A) Netter's Atlas of Human Anatomy. (B) Pernkopf's Topographical Anatomy of Man. The numbers and highlights are used for cross referencing anatomical landmarks in the following surgical photos. (The authors explicitly honor the memory of the subject portrayed in the Endtresser's painting from the Pernkopf's atlas.)

of the saphenous nerve. There was no other surgeon available with experience in this surgical exposure, and no other accessible anatomical resource that described the exposure in adequate detail. In this case study, the first author (Yee) emailed the senior author (Mackinnon) the requested, appropriate images from Pernkopf's atlas, on the basis of which the surgery was successfully completed thereafter. The decision to use Pernkopf's atlas was based on having exhausted all other options and meeting the criteria of an ethical "checklist" as described.

In this specific surgical case (Fig. 6.3), the following procedural steps outline the anatomical and surgical utility of Pernkopf's atlas:

1. Retraction of the superficial muscles (sartorius) to reveal the deeper layers, providing appropriate exposure to the anteromedial (vasto-adductor) intermuscular septum.

2. Protection of the anterior femoral cutaneous nerve upon approach and its distal innervation of the anterior/medial aspect of the knee.
3. Illustration of the saphenous nerve and its two distal nerve branches, which includes a communication branch for the medial femoral cutaneous nerve.
4. Lateral positioning of the saphenous nerve in respect to the femoral vessels.
5. Depiction of the septum tunnels from which the saphenous branches and vessels pierce.
6. Illustration of the vascular pedicle to the sartorius muscle.

The routine approach for nerve decompression in cubital tunnel surgery, median nerve in the forearm release, posterior interosseous nerve release, and others is to identify the nerve proximally and follow its distal course for clear visualization and release of the intended anatomical structures. Release of the saphenous nerve is the opposite, in that you must have deep knowledge of the adjacent structures that obscure the nerve and identify other landmarks for decompression. Specifically, the saphenous nerve is hidden beneath the anteromedial intermuscular septum and there exist small cutaneous nerves with similar trajectories that can be easily confused for the saphenous nerve. Palpating for the femoral artery orientates the dissection to look for the superior position of the saphenous nerve after a careful and blinded incision of the septum for exposure. These subtle and technical steps illustrate the dissection's difficulty and the involved potential frustration, in which a prominent surgical resource can alleviate and provide guidance.

FIGURE 6.3. Saphenous nerve release for managing neuropathic pain. Numbers are for referencing Pernkopf's illustration on the previous figure. (A) Exposure of saphenous nerve. (B) Decompression of saphenous nerve through release of the anteromedial intermuscular septum. (M - muscle, N - nerve.)

ETHICS BOTTOM LINE: RETURN TO THE O.R.

The continued use of Pernkopf's atlas in clinical medicine presents an ethical dilemma that is multi-faceted, complex, and debatable in nature. This requires a definitive judgment call that must be made by the surgeon within the operating room, on how to further proceed with the case. When faced with ethical dilemmas, ethically grounded surgeons consider all clinically defensible options and the foundational information in the case (i.e. "all things considered") and then make decisions based on their professional responsibilities and moral values. As an unusually detailed anatomical atlas, the Pernkopf atlas' utility in informing complex or rare surgical problems is in tension with its ethically tainted origin, including the authors' ties to the Nazi regime and unclear origins of some of the bodies depicted. A surgeon or other clinician presented with a problem that requires consultation with a detailed anatomy reference should be aware of the history behind Pernkopf's atlas when deciding whether or not to use it. Ethical justifications can be and have been made for several options, from promoting the use of the atlas to honor the Nazi victims whose bodies were used in the creation of the anatomical illustrations, to removing the atlas entirely from medical libraries around the world. Nonetheless, the atlas is likely to persist in circulation in the medical community, especially in surgery, and transparency towards the historical facts and unanswered questions regarding its origin should be part of the discussion regarding its ethical handling in modern medical practice. An ethical use of images from Pernkopf's atlas should be subject to strict conditions and limitations, integrating the focus on saving the life of a patient with the memorialization of the persons whose bodies were used for the creation of the images.³¹ The Pernkopf story and the application of the atlas in surgical patient care can serve as an ethical case study in the medical education and advanced training of surgeons.

6

OUTCOME OF SURGERY

In this case study, the patient involved with the use of Pernkopf's atlas recovered from the effects of the surgery, and despite a large scar, was gratifyingly free of pain for the first time in many years.

REFERENCES

1. Jones DG. Anatomy and ethics: an exploration of some ethical dimensions of contemporary anatomy. *Clin Anat*. 1998;11(2):100-105.
2. Jones DG, Whitaker MI. *Speaking For the Dead: The Human Body in Biology and Medicine*. Farnham, England: Ashgate; 2009.
3. Williams DJ. Is a picture worth a thousand lives? The truth about the most beautiful book you will never see. The twenty-third annual Charles Henry Hackley distinguished lecture in the humanities.; May 20, 2004, 2004; Muskegon, Michigan.
4. Angetter DC. Anatomical science at University of Vienna 1938-45. Senate Project of the University of Vienna. *Lancet*. 2000;355(9213):1454-1457.
5. Malina P, Spann G. Das Senatsprojekt der Universität Wien "Untersuchungen zur Anatomischen Wissenschaft in Wien 1938-1945". *Wien Klin Wochenschr*. 1999;111(743-53).
6. Weissmann G. Springtime for Pernkopf. *Hosp Pract (Off Ed)*. 1985;20(10):142-168.
7. Williams DJ. The work of Eduard Pernkopf, et al. 37th Annual Meeting of the Association of Medical Illustrators; 1982/10/13, 1982; Anaheim, CA.
8. Williams DJ. The history of Eduard Pernkopf's Topographische Anatomie des Menschen. *J Biocommun*. 1988;15(2):2-12.
9. Akademischer Senat der Universität Wien. Senatsprojekt der Universität Wien: Untersuchungen zur Anatomischen Wissenschaft in Wien 1938-1945. (Unpublished Manuscript). In: Akademischer Senat der Universität Wien.; 1998.
10. Atlas MC. Ethics and access to teaching materials in the medical library. *Med Law*. 2000;19(3):463-473.
11. Atlas MC. Ethics and access to teaching materials in the medical library: the case of the Pernkopf atlas. *Bull Med Libr Assoc*. 2001;89(1):51-58.
12. Israel HA, Seidelman WE. Nazi origins of an anatomy text: the Pernkopf atlas. *JAMA*. 1996;276(20):1633; author reply 1634.
13. Israel HA, Seidelman WE. Origins of the Pernkopf anatomy atlas: In reply. *JAMA*. 1997;277:1123.
14. Norton SA. On first looking into Pernkopf's atlas (part 1). *Arch Dermatol*. 2001;137(5):549-551.
15. Riggs G. What should we do about Eduard Pernkopf's atlas? *Acad Med*. 1998;73(4):380-386.
16. Carstens PA. Revisiting the Infamous Pernkopf Anatomy Atlas: Historical Lessons for Medical Law and Ethics. *Fundamina*. 2012;18(2):23-49.
17. Yee A, Coombs DM, Hildebrandt S, Seidelman WE, Coert JH, Mackinnon S. Nerve Surgeons' Assessment of the Role of Eduard Pernkopf's Atlas of Topographic and Applied Human Anatomy in Surgical Practice. *Neurosurgery*. 2018.
18. Fackenheim EL. *To Mend the World: Foundations of Post-Holocaust Jewish Thought*. Bloomington, Indiana: Indiana University Press; 1994.
19. Polak JA. "Vienna Protocol" for when Jewish or Possibly-Jewish Human Remains are Discovered. In: Seidelman WE, Elbaum L, Hildebrandt S, eds. *How to Deal with Holocaust Era Human Remains: Recommendations arising from a special symposium*. Boston, MA: Elie Wiesel Center for Jewish Studies, Boston University; 2017.
20. Kahn LC, Yee A, Mackinnon SE. "Important Details in Performing and Interpreting the Scratch Collapse Test". *Plast Reconstr Surg*. 2017.
21. Ernst E. A leading medical school seriously damaged: Vienna 1938. *Ann Intern Med*. 1995;122(10):789-792.
22. Muehlberger K. Enthebungen an der medizinischen Fakultät 1938-1945. *Wien Klin Wochenschr*. 1998b;110:115-120.
23. Hutton EB. Nazi Origins of an Anatomy Text: The Pernkopf Atlas-Reply. *JAMA*. 1997;276(20):1634.
24. Weissmann G. Origins of the Pernkopf anatomy atlas. *JAMA*. 1997;277(14):1122; author reply 1123-1124.
25. Ebenbauer A, Schuetz W. Origins of the Pernkopf anatomy atlas: In reply. *JAMA*. 1997;277:1123-1124.
26. Schwarz P. NS-Justiz, Todesstrafe und Hinrichtung am Landesgericht Wien unter besonderer Berücksichtigung frt zum Tode verurteilten jüdischen Opfer. In: Akademischer Senat der Universität Wien. 1998. Senatsprojekt der Universität Wien: Untersuchungen zur anatomischen Wissenschaft in Wien 1938-1945. In. Unpublished Manuscript. 1998:93-141.
27. Hildebrandt S. Current status of identification of victims of the National Socialist regime whose

- bodies were used for anatomical purposes. *Clin Anat.* 2014;27(4):514-536.
28. Hildebrandt S. How the Pernkopf controversy facilitated a historical and ethical analysis of the anatomical sciences in Austria and Germany: a recommendation for the continued use of the Pernkopf atlas. *Clin Anat.* 2006;19(2):91-100.
29. Hubbard C. Eduard Pernkopf's atlas of topographical and applied human anatomy: the continuing ethical controversy. *Anat Rec.* 2001;265(5):207-211.
30. Hildebrandt S, Seidelman WE. Where do they come from? A call for complete transparency regarding the origin of human tissues in research. *ESMO Open.* 2017;2(2):e000201.
31. Hildebrandt S, Seidelman WE. To use or not to use: The legitimacy of using unethically obtained scientific results or human tissue from the National Socialist era. *Wiener Klinische Wochenschrift.* 2018;130(3):S228-S231.
32. MacNeil-Lehrer Report. PBS. **August 1, 1988**, 1988.
33. Berger RL. Nazi science--the Dachau hypothermia experiments. *N Engl J Med.* 1990;322(20):1435-1440.
34. Mueller FH. Tabakmissbrauch und Lungencarcinom. *Zeitschrift für Krebsforschung.* 1940;49(1):57-85.
35. Pozos R. Can scientists use information derived from concentration camps? Paper presented at: Conference on the Meaning of the Holocaust for Bioethics; May 17-19, 1989, 1989; Minneapolis, MN.
36. Proctor RN. *The Nazi War on Cancer.* Princeton, NJ: Princeton University Press; 1999.
37. Proctor RN. Nazi science and Nazi medical ethics: some myths and misconceptions. *Perspect Biol Med.* 2000;43(3):335-346.
38. Schairer E, Schoeniger E. Lungenkrebs und Tabakverbrauch. *Zeitschrift für Krebsforschung.* 1944;54(4):261-269.
39. Shabecoff P. Head of E.P.A. Bars Nazi Data In Study on Gas. The New York Times Company. The New York Times Web site. <http://www.nytimes.com/1988/03/23/us/head-of-epa-bars-nazi-data-in-study-on-gas.html>. Published 1988. Accessed.
40. Hildebrandt S. *The Anatomy of Murder: Ethical Transgressions and Anatomical Science during the Third Reich.* New York: Berghahn Books; 2016.
41. Roelcke V. Medicine during the Nazi Period: Historical Facts and Some Implications for Teaching Medical Ethics and Professionalism. In: Rubenfeld S, ed. *Medicine after the Holocaust.* New York: Palgrave MacMillan; 2010:17-28.
42. Hayek H. *Die menschliche Lunge.* Berlin: Springer-Verlag; 1953.
43. Stieve H. *Der Einfluss des Nervensystems auf Bau und Tätigkeit der Geschlechtsorgane des Menschen.* Stuttgart: Thieme; 1952.
44. Voss H, Herrlinger R. *Taschenbuch der Anatomie.* Jena: Gustav-Fischer-Verlag; 1946.
45. Matuchansky C. Naming of the victims of Nazi medicine. *Lancet.* 2017;390(10098):933.
46. Ball P. Naming the victims of Nazi medicine. *Lancet.* 2017;389(10085):2182-2183.
47. Steinberg A. In: Rosner F, trans. *Encyclopedia of Jewish Medical Ethics.* Jerusalem, Israel and Nanuet, NY: Feldheim Publishers; 2003.
48. Moulton CA, Regehr G, Lingard L, Merritt C, MacRae H. Slowing down to stay out of trouble in the operating room: remaining attentive in automaticity. *Acad Med.* 2010;85(10):1571-1577.
49. Yang RL, Esquivel M, Erdrich J, Lau J, Melcher ML, Wapnir IL. PREDICT: Instituting an Educational Time Out in the Operating Room. *J Grad Med Educ.* 2014;6(2):382-383.
50. Langerman A, Angelos P, Siegler M. The "call for help": intraoperative consultation and the surgeon-patient relationship. *J Am Coll Surg.* 2014;219(6):1181-1186.
51. Yurko YY, Scerbo MW, Prabhu AS, Acker CE, Stefanidis D. Higher mental workload is associated with poorer laparoscopic performance as measured by the NASA-TLX tool. *Simul Healthc.* 2010;5(5):267-271.
52. Coombs DM, Peitzman SJ. Medical Students' Assessment of Eduard Pernkopf's Atlas: Topographical Anatomy of Man. *Ann Anat.* 2017;212:11-16.
53. Hippocratic Writings. In: 2nd ed. London: Penguin Books:94.

CHAPTER 7

SUMMARY, DISCUSSION, AND FUTURE PERSPECTIVES

Related Press:

Baker K. Eduard Pernkopf: The Nazi book of anatomy still used by surgeons. BBC. August 19, 2019.

Begley S. The surgeon had a dilemma only a Nazi medical text could resolve. Was it ethical to use it? STAT, May 30, 2019.

Kershner, I. In Israel, Modern Medicine Grapples with Ghosts of the Third Reich. The New York Times, May 12, 2020.

SUMMARY

The dissemination and implementation (D&I) of innovation is a vital and active process for the advancement of surgery.^{1,2} There exist several frameworks that describe various stages of innovation to promote translation of knowledge and research into clinical practice.³ The IDEAL framework has been used internationally to improve the quality of research and emphasis rigorous assessment and reporting of outcomes for novel procedures in surgery.⁴ Despite these validated approaches, the process from ideation to implementation can take many decades – an estimated 17 years for 14% of medical research to translate from benchtop to bedside and influence patient care.⁵ Expert performance is an approach to identify superior performance, capture it, and reproduce this performance towards achieving a state of mastery.⁶ Individuals who exhibit mastery in surgery can be considered hubs for innovation,⁷ especially in specialties that have an illustrious history of innovation and shift in management paradigms such as in nerve surgery.^{8,9} These master surgeons are considered expert performers, excellent teachers and coaches, and compelled to share their expertise. To capture expertise, video is an effective visual medium to facilitate deliberate practice and learn operative skills and clinical reasoning.¹⁰ In this thesis, a video-based learning program was developed as an educational framework and active D&I process to promote expertise and innovation in nerve surgery.

The ethical development of innovative procedures is paramount to any surgical discipline, and mandates robust evaluation for safety, efficacy, and effectiveness.¹¹ A major proponent of ethics in surgical innovation are surgeon educators, whose guidance help reduce the learning curve for the safe diffusion and adoption of new techniques.¹² In a specialty of innovation and anatomy, plastic and reconstructive surgeons often require creative strategies to manipulate anatomy to reconstruct uncommon or complex defects. At this intersection of surgery, anatomy and education, ethical issues can arise regarding the origins from which data and human tissues are sourced.¹³ In designing training methods to translate expertise and reduce learning curves, an ethical dilemma was encountered regarding the use of an anatomical atlas, known for its accurate portrayal of the nervous system however sourced from victims of the Third Reich,¹⁴⁻¹⁶ in surgery and education. To acknowledge the victims of medical crimes, surgeons' opinions were assessed on a proposal for the appropriate disclosure, bioethics and religious considerations, and remembrance. Furthermore, an ethical framework was presented to guide surgeons in the consideration and use of Pernkopf's atlas in surgery and education.

The aim of this thesis was to develop an educational framework for the translation of expertise and dissemination and implementation of surgical innovation by (1) establishing video-based learning as an approach to learn operative skills and clinical reasoning in surgery, and (2) addressing the related ethical implications in the anatomical sciences.

PART I: ESTABLISHING VIDEO-BASED LEARNING IN NERVE SURGERY

A video of surgery is a rich source of visual data and considered by some “worth a thousand operative notes.”¹⁰ Using Ericsson’s approach of expert-performance, an educational program was built using videos to promote innovation in nerve surgery.^{6,17} The program started in 2011 and was built using an iterative design process to construct a custom and interactive video-based learning platform and report its effectiveness using learning analytics. To determine the role of video for learning surgical expertise, (1) a surgical video of a simple procedure was examined to improve technical skill and (2) an effective video-based module was developed to teach clinical reasoning and accompany our videos on surgical procedures.

In **Chapter 2**, the longitudinal development and effectiveness of an international video-based learning program in nerve surgery were described using learning analytics. In 2011, an online educational resource called *Nerve Surgery* (nervesurgery.wustl.edu) was launched and reported 67K+ user sessions and 16K+ video views in its first 2 years. To improve audience outreach, *YouTube* was leveraged to publish 117 nerve surgery videos, which attained 3M+ views from 165+ countries in 7 years. From 2016-2018, this international viewership (69% originating outside the United States) was channeled into 1,700+ registered users on *PASSIO* (passioeducation.com), a custom and interactive video-based learning platform with integrated learning analytics. Of the registered users, 43% were active on *PASSIO* for at least once a month. These analytics established a surgeon viewing engagement of 48% and documented a decline in viewer engagement with increased video duration. However, more importantly, audience retention between our instructional short and long video formats of surgery were correlated. Additionally, surgeons preferred longer videos when preparing for infrequent or difficult cases compared to routine cases, opposing the notion that educational videos should be 10 minutes or less.^{18,19} This body of work demonstrated the creation of an online community in nerve surgery and effective spread of best practices through the joint use of *YouTube* for audience outreach and a surgeon-focused video platform to maximize educational value.

In **Chapter 3**, the role of a surgical video was examined in learning an operative procedure. In this study, 22 residents (PGY 1-6) were randomized to prepare for a simulated surgery in a donor body by using either a distinguished hand surgery textbook²⁰ or this textbook supplemented with a surgical video to perform a carpal tunnel release. Both the textbook chapter and video were authored and illustrated by the same authors (Mackinnon and Yee). Resident performance was filmed and graded by a blinded panel of surgeons using an objective structured assessment of technical skill (OSATS) and a modified version of a validated grading scale specific to this procedure.^{21,22} Junior residents (PGY 1-2) who watched the surgical video performed fewer operative errors (median 1.3 vs 4) and were more confident in their technical abilities (median 75 vs 32). This study demonstrated that observing surgery is essential to learning a new procedure by reducing operative errors and improving confidence. This study also emphasized the importance of an online

learning platform to integrate a video into a more robust educational module to accommodate deficits in technical skill.

In **Chapter 4**, educational videos were examined to effectively teach clinical reasoning or judgment for patient selection in surgery and promote safe adoption and implementation of a novel procedure. In this study, a captivating video-based learning module was designed to describe electrodiagnostic indications for cubital tunnel surgeries to include the supercharge end-to-side (SETS) nerve transfer.²³ The module and videos were developed using instructional design principles based from the cognitive theory of multimedia learning (CTML).^{24,25} The videos were uniquely produced using a “whiteboard” and dynamic slide transitions to emphasize spatial association of key concepts.^{26,27} Pre- and post-lecture and retention knowledge assessments were used to determine knowledge acquisition. The module was well-received with 279 surgeons spending at least 30 minutes watching the video(s), reinforcing our notion that surgeons will watch a video for more than 10 minutes when the user experience and lecture are exceptionally designed to teach clinical reasoning. The module was also timed to address a knowledge gap based from surgeon feedback on “the main reason for performing the SETS nerve transfer.”^{28,29} Knowledge scores improved by 3 points (10-point scale) and knowledge retention persisted at 3 months, thereby demonstrating potential long-term practice change and the effectiveness of a video-based module to teach clinical reasoning for surgery.

PART II: ADDRESSING ANATOMICAL ETHICS IN SURGICAL INNOVATION

The procedures defined in our video-based learning program were in part influenced by the study of Pernkopf’s atlas of human anatomy. However, this atlas is shrouded in controversy due to the initial revelations of Eduard Pernkopf and his medical illustrators’ affiliation to the Nazi Party (NSDAP).^{15,16} In the 1990s, an international inquiry led to the commission of the *Senatorial Project of the University of Vienna*, which ascertained the unethical anatomical body acquisition of executed victims of the Nazi regime, which were depicted in the atlas.¹⁴ Undoubtedly, the atlas influenced the development of new surgical techniques in nerve surgery due to its anatomically accurate representation of the nervous system. To consider its use in surgical innovation and education, we must first address the bioethical issues related to the use of images derived from the physician atrocities of the NSDAP during the Holocaust.³⁰

In **Chapter 5**, surgeon opinions regarding the use of the Pernkopf atlas in surgery and education were assessed to develop a four-point proposal for its ethical handling. Two specialties were surveyed, nerve surgery and oral & maxillofacial surgery, to consider the atlas’ two printed volumes (I – Head and Neck, and – Thorax, Abdomen, and Extremities) and the accurate portrayal of the nervous system and head and neck anatomy. In total, 364 surgeon responses were collected and indicated 54% awareness of the atlas and 16% currently using it in surgery. Of those aware of its historical origin, 56% felt comfortable using the atlas in surgery. Attitudes from

the oral & maxillofacial surgery (OMS) towards the atlas tended to be more reserved than nerve surgeons, which may be explained by an older demographic in OMS and the depiction of facial features of the victims. A 4-point proposal to include disclosure, bioethics and religious considerations, and remembrance shifted 76% of those “uncomfortable” or “undecided” to becoming “comfortable” with the atlas. In all 10 anatomical plate comparisons, surgeons indicated that Pernkopf’s atlas provided greater anatomical detail and surgical utility compared to Netter’s atlas. In summary, this combined study provided insight into the perspectives of surgeons on the use of Pernkopf’s atlas in surgery and education.

In **Chapter 6**, ethical and religious guidelines for the use of Pernkopf’s atlas in surgery were presented and based on a four-option framework of applied ethics to provide practical methods for confronting bioethical dilemmas.³¹ This included a responsum – the Vienna Protocol – by Rabbi Joseph A. Polak, a Holocaust survivor and Chief Justice of the New England rabbinical courts, who formulated guidelines on the use of the atlas based on Jewish medical ethics.^{32,33} A study was presented, in accordance to the four-option framework, of a patient case in which the use of the atlas was necessary to successfully complete the surgery. The four-options to navigate the bioethical dilemma when encountering difficulty in surgery includes (1) recognizing the need for a timeout, (2) calling a colleague for emergency consultation, (3) consulting ethical anatomical resources, and if required, (4) consulting the Pernkopf atlas with respect, gratitude, and in recognition of the victims’ lives and suffering. This study provides the bioethical and, in part, religious considerations suggested in the four-point proposal for the ethical use of Pernkopf’s atlas in surgery and education.

CONCLUSION

Video-based learning is an effective approach for the dissemination and implementation of surgical innovation and sharing best practices when guided by principles of evidence-based medicine and the CTML. When produced carefully and elegantly, educational videos can be valuable to learning expert technical skills and clinical reasoning. The development of an interactive online platform using effective instructional design can cultivate a captivating learning environment to create communities in surgery and become a foundation to disseminate critical knowledge and implement education research. Ethical issues encountered in surgical innovation, such as the Pernkopf’s atlas, can use this platform to improve historic awareness in the anatomical sciences and implement ethical guidelines. The proposed educational framework using video-based learning warrants identifying qualified expert or master surgeons to expand training opportunities in surgery that transcend geographic, economic, racial, gender, and language barriers and address disparities in healthcare across the world.

DISCUSSION

In this section, we will review the work of this thesis from a broad perspective, discuss new findings and contributions to the field, and describe the challenges yet to overcome. We will also discuss the work in the context of dissemination and implementation. Furthermore, we will discuss the future of video-based learning in the development of a model for continuing professional development and future ethical challenges to overcome regarding the Pernkopf controversy.

ESTABLISHING SURGEON ENGAGEMENT IN VIDEO-BASED LEARNING

Research involving videos in medical education began when Prober and Khan introduced a “flipped classroom” model that was based on more than five years of experience producing and uploading educational “whiteboard” videos to *YouTube*.¹⁸ They proposed creating short 10-minute videos without clear evidence or methodology except that the “best” videos would emerge over time. Surgical videos, videos that teach a specific operative procedure, have experienced rapid and widespread adoption that has at times outpaced quality and safety control.³⁴ Due to the substantial variability of quality and educational value in these videos,³⁵⁻³⁸ a LAP-VEGaS consensus statement by an expert committee of joint trainers and trainees offered 37 guidelines to standardize and improve the educational quality of videos in laparoscopic surgery.³⁹ In a subsequent editorial, Ritter empathized the need to optimize videos for learning by managing cognitive load, tailoring content to different levels of expertise, maximizing audience engagement, and keep Prober and Khan’s suggestion to limit video duration to under 10-minutes.¹⁹ Despite the fact that surgeries vary greatly in time and complexity, surgeon engagement in educational videos have not yet been defined, along with factors that influence preferred video duration. Two studies defined audience engagement by examining 862 educational videos on a massive open online course and 5.3 million videos on *YouTube*, depicting a logarithmic decline in audience engagement with increasing video duration.^{40,41} Only one study in medicine examined 10 video lectures of electroencephalography interpretation on *YouTube* produced by one principal author, and used learning analytics to define a similar decline in audience engagement.⁴² In **Chapter 2**, a similar pattern of decline in audience engagement was found with a mean engagement of 34.4% on *YouTube* with 117 educational videos produced by one principal author, and defined a significantly higher audience engagement in surgeons (48.4%) using a video-based learning platform designed for surgeons. These findings established a benchmark for viewing engagement which can be used as a reference for surgeon educators.⁴¹

As Ritter emphasized in tailoring content to different levels of expertise,¹⁹ two types of surgical videos were created for surgeons to learn an operative procedure: short and long video formats (Fig 7.1). These formats were a result of a careful production workflow to create instructional surgical videos. Both formats included all operative steps, where the **long video included the cadence of the procedure to de-**

pict surgical flow,⁴³ while the **short video was created for just-in-time learning**.⁴⁴ These surgical videos were specifically designed for both novice and experienced surgeons to develop a mental state of surgical flow and expertise which promotes remaining attentive during automaticity.^{45,46} For example, written feedback from surgeons using these videos corroborated findings that practicing surgeons new to a procedure carefully studied the long video several times, often days before the operation, and described use of the short video as a “refresher” to promote mental rehearsal and actual execution of the learned motor actions.⁴⁷⁻⁴⁹ This could explain one surgeon’s comment: “after watching [the videos] several times without difficulty, although it was my first time [performing the procedure] – it felt like it was my 100th time.” As reported in our survey of 304 surgeons, they also described using the short video to understand key learning points of a procedure before investing valuable time into the long video. Additionally, surgeons who gained enough experienced, the short video became an excellent learning tool for routine cases or having limited preparation time before a case. Remarkably, surgeon engagement, specifically relative audience retention curves, confirmed similar viewing behaviors between the short and long videos and were significantly corrected ($t_b = 0.52$, $P < 0.0001$), demonstrating our intended use of the videos for learners. In summary, the study in **Chapter 2** supports the production of variable-duration (short and long) videos to promote expertise in learning operative skills.

FIGURE 7.1. Thumbnails for short- and long-format surgical videos. The thumbnails were designed to identify our short and long videos easily across different publishing channels and video platforms. The displayed thumbnail included the introduction slide (title, authors, abstract, and affiliations) and a key video frame from the procedure. The surgery displayed is the Furrow double opposing z-plasty procedure for secondary palatoplasty. The short and long videos have the “standard” and “extended” flag, respectively.

The challenges of our video-based learning model must be viewed in the context of D&I science.¹ The educational program was originally developed to disseminate surgical innovation and expertise in nerve surgery using videos, while evidence for implementation was collected using learning analytics and surgeon surveys. Having surgeons report their outcomes would have been ideal, however there does not exist a systematic and practical method to collect this type of data. In **Future Perspectives**, the model of video-based surgical coaching is described as the next logical step of our educational program to attain superior evidence of implementation.⁵⁰⁻⁵² The proposed additional model would have surgeons submit videos of their surgery for expert review, which would provide (1) a rich source of visual performance data

for analysis,⁷ (2) an opportunity for learners to receive expert feedback to improve their performance,⁵² and (3) feedback for educators to improve their learning interventions. Even photos of specific steps in surgery can be an easy and valuable source of performance data to collect (i.e. Is the pronator-flexor fascial sling too tight during a transmuscular ulnar nerve transposition or is the nerve coaptation during a nerve transfer free of tension?).

An additional challenge in our video-based learning model is its generalizability to other surgical specialties. In our experience, authors should be opinion leaders with the following 3 characteristics:^{1,17} individuals with (1) expertise in focused clinical areas that demonstrate both clinical and technical proficiencies, and (2) experience practicing, teaching, and coaching in an academic surgical environment. These master surgeons should also be interested and proficient, above else, in (3) sharing their knowledge in sufficient detail to facilitate the implementation of best practices. These masters have acquired an automated processing in their decision-making,^{45,46} and perhaps forgetting how they originally learned this information. In a controversial study, surgeon academic performance was associated with clinical outcomes in the clipping of ruptured intracranial aneurysms.⁵³ Individuals with high academic performance would likely be a recruit to further develop this model. As a proof of concept, we have produced and measured 12 additional videos with 4 master surgeons, who are considered opinion leaders in their respective fields and renowned educators. These videos performed similarly to the 117 nerve surgery videos (Table 2.3). We encourage surgeon educators to evaluate a similar video-based learning model in their own online educational programs and report their analytics data.⁵⁴

SURGICAL VIDEO IMPROVES PERFORMANCE BY REDUCING OPERATIVE ERRORS

Surgeon feedback have depicted the immense benefits of learning operative skills using our high-quality videos, voiced over by expert surgeons, and photos to illustrate the surgical steps of a procedure. Having established surgeon engagement and channels to disseminate educational videos internationally, there was a need to study the role of an individual surgical video in learning operative skill in a cadaveric simulation-based study. In **Chapter 3**, junior residents who were inexperienced with a procedure performed fewer operative errors when using a video to prepare for surgery than those using a textbook alone. A carpal tunnel release was chosen as the procedure to examine due to (1) its relative simplicity compared with our entire library of videos in nerve surgery, (2) a commonly performed and routine procedure advised by our learning analytics for being the most viewed video, and (3) the existence of an objective structured assessment of technical skill (OSATS) for this specific procedure.²² Junior residents in the video group may have actually performed better than their peers during the OSATS despite non-significant differences in global and technical rating scores. Indeed, the video group did score higher in all performance measures, however, sample sizes in our subgroup analyses could not reliably detect true differences between intervention groups. The post-hoc power was 0.44 for the global score in the PGY1-2 subgroup, suggesting that more than

twice as many participants would have been required to achieve at least 80% power at a 95% confidence level. The challenge was that the cadaveric simulation-based study required substantial resources, including the time to evaluate each performance, which limited the number of participants who could be enrolled. Having demonstrated acceptable agreement between evaluators who were board-certified hand surgeons, only two evaluators could have been used to reduce time commitment.⁵⁵

An additional challenge of the study was that the video may not have been optimized for the specific needs of less experienced trainees. For example, a majority of junior residents in the video group made errors involving the initial skin incision, and the video could have devoted more time demonstrating this important step. This highlights the importance to teach the placement of incisions in relation to anatomical landmarks, otherwise surgeons could compromise their operation by entering the wrong anatomical plane, especially for procedures that they are unfamiliar with. A recent study emphasized incision placements by using online animations to teach preoperative markings for cleft lip repair to medical students.⁵⁶ This incision animation was later incorporated into a more robust simulation, which combined other animations with intraoperative videos, to effectively teach unilateral cleft lip repair to residents.⁵⁵ Similarly, junior performance in our study may have improved from additional learning modules describing incision placement and relevant anatomical structures, as noted by the 42% of trainees “wanting more detail” in their description of a weakness in the simple surgical video. At the time of this study, we were in the process of constructing our video-based learning platform to offer integration of connected modules with an in-depth description of incision placement, interactive video chaptering system (table-of-contents), and description of its key steps. Therefore, we could not offer this more comprehensive modality of learning, however, the insight gained from this study advised in the effective development of our video platform.

7

COMPELLING EDUCATIONAL VIDEOS TEACH CLINICAL REASONING

Learning clinical reasoning – who, what, when, and why to perform a procedure – with operative skills is an essential part in surgery for achieving optimal outcomes.⁵⁷⁻⁶⁰ Performing the wrong operation or at the wrong time will produce a poor result, thus deterring surgeons from becoming *first adopters* of evidence-based surgical innovations (Fig. 1.1). For example, with neurotmetic injuries (nerve transection), motor nerve transfers are typically indicted only within the first year after nerve injury due to chronic muscle denervation of the motor endplates over time,⁶¹ versus compression neuropathy and axonometric injuries which are not as time limited.⁶² Teaching clinical reasoning warrants a separate video format due to the depth of knowledge required to learn how to safely implement novel surgical techniques. Traditionally, this information is learned through peer-reviewed publications and instructional courses and lectures at annual conferences. Our novel approach in this thesis was to convert evidenced-based interventions into compelling educational

video lectures, produced using spatial learning and concept maps,²⁶ to design a module that incorporated best practices from the CTML.⁶³ This module and videos could be used as reusable learning objects and re-watched,⁶⁴ unlike the single sessions provided at the instructional courses. **Chapter 4** described one of the highest surgeon engagement (279 nerve surgeons) in an online educational study, most likely due to the nature of the content and its timing and relevance to the latest advances in the SETS nerve transfer. The need to describe specific indications for this procedure came from e-mails and surgeon discussion forums pertaining to “the main reason for doing the SETS nerve transfer.” Only recently, indications were refined for this procedure,²⁸ by revising classifications for cubital tunnel syndrome to include compound motor action potential (CMAP) amplitude as an indicator of axonal loss and disease severity,^{65,66} rather than the traditional teaching of a decrease in conduction velocity at the elbow.²⁹

CTML had a prominent role in the instructional design of the educational module and video lectures.^{63,67} When examining this study through the lens of cognitive load and example-based learning,⁶⁸ great efforts were made to optimize intrinsic load and reduce extrinsic load in our learning materials.^{19,69} For example, the questions in the pre- and post-lecture assessments were carefully sequenced in an order that mimicked the diagnostic approach used in the algorithm to manage cubital tunnel syndrome,⁷⁰ which served as the focus of the learning intervention.^{28,29} To prompt learners to the lectures and reveal deficits in their clinical knowledge,²⁵ incorrect answers were summarized following the pre-lecture assessment. The lectures, themselves, included worked-examples of real clinical cases and electrodiagnostic reports (nerve conduction studies and electromyography) to depict polymorphisms for material encountered in everyday practice.^{71,72} Due to the initial complexity of the electrodiagnostic reports (these can differ between neurologists), the reports were reordered and corrected to be consistent between examples and presented the reports using cuing and perceptual highlighting to reduce intrinsic load.⁷³ Steps were also taken to reduce the extrinsic load of the learning materials by producing a high-quality 2K (2560 x 1440 resolution, 16:9 aspect ratio) video. The principal author who voiced-over the lecture was also green-screened and displayed in the lower right-hand corner of the video.

To reduce the risk of expertise reversal effect and accommodate for different levels of knowledge,^{74,75} a full-length lecture (28-minutes) and an abridged version of the lecture (7-minutes) were created to summarize the recent decision algorithm for cubital tunnel syndrome.^{28,29} Although the full lecture used spatial learning to elegantly transition between worked-examples of clinical cases and depict its contextual relationship to the algorithm (Fig. 7.2),⁷⁶⁻⁷⁸ the abridged lecture was specifically designed for the experienced surgeon, who just wanted a quick review of the relevant electrodiagnostic reports. This abridged lecture progressed through key examples using linear slide transitions. The clinical cases were also presented using the principle of fading, where examples were structured with increasingly more complex diagnostic steps.⁷⁹ Remarkably, surgeons spent at least 30 minutes learning from the lectures, disputing a notion to limit videos to 10 minutes or less,^{18,19} and on average, surgeons returned to watch the lectures over two viewing sessions. These

ALGORITHM

FIGURE 7.2. Visual depiction and flow of a video-based learning module for clinical reasoning. A diagnostic and management algorithm for cubital tunnel surgery was designed to illustrate worked-examples of clinical cases and its relationship to the algorithm. The arrow depicts the spatial flow (zoom-in and -out) of the video lectures.

A couple of challenges were encountered during the study that could affect its effectiveness to teach clinical reasoning. The first was that we were experiencing a technology and video migration from *PASSIO* to *Learn Surgery*, which resulted in the loss of several core features and functionality, which included new user registrations and management and video chaptering systems. Therefore, the study was manually administrated using a survey tool and required significant research coordination to recruit participants, distribute the module, follow-up, send reminder e-mails, and facilitate providing continuing medical education credits. Despite this study recruiting 279 surgeons from our international community of nerve surgeons, this number may have been higher if these processes were automated – which was a pillar in *PASSIO*'s design philosophy to build an attractive learning environment. Another challenge that we encountered was related to the problem-solving component of the pre- and post-lecture assessments, where surgeons were given an electrodiagnostic report to analyze and determine whether they could identify a conduction block or indicate a SETS nerve transfer. In both questions, surgeons significantly improved their knowledge after watching the video(s), however did not reach a level of acceptability found in the other multiple-choice questions (Table 4.2). When examining audience retention in these lectures, the respective decline in viewing engagement was found, which may be explained by cognitive load – high intrinsic load required in the information presented. While this warrants further investigation to redesign the module, this knowledge deficit could be easily remedied with a follow-up educational module to improve surgeon knowledge and report the study findings. As a limitation of the study, we were unable to confirm self-reported practice change or measure differences in clinical outcomes. While this limitation is shared by several studies evaluating multimedia learning,⁸² surgeons could submit this information using video-based surgical coaching, as proposed in **Future Perspectives**, to demonstrate long-term practice change.

ADVANCING ANATOMY ETHICS IN SURGERY

The study of the ethical issues regarding the use of Pernkopf's atlas in surgery has been a remarkable and narrative journey to see individuals from diverse backgrounds come together and support a solution of the controversy surrounding its use based on ethical and historical awareness.⁸³ At the beginning of this study, it was not foreseeable that the journey to provide equitable training for nerve surgeons would allow surgeons to reflect and consider the ethics of using an atlas derived from the Holocaust (*Shoah*).^{84,85} While Mackinnon had spent many years with the atlas as her dissection partner before Gerald Weissman and David Williams published essays exposing its 'evil' origin in the late 1980s, I spent a brief period also being unaware of the atlas' origins and became fascinated while dissecting the nervous system with a surgical fellow. While being assigned to develop our first educational website called *Nerve Surgery*, the atlas was first introduced to me by the fellow without full disclosure. Having already spent several years dissecting and being a teacher assistance in the anatomy lab, the fellow and I proposed creating select anatomical photo plates of the nervous system (Fig. 7.3), where we consulted the dissections portrayed in the atlas with a focus on the peripheral nerves. I was

7

The “equilibrium” regarding the use of the atlas sufficed until 5 years ago, when the ethics issues re-surfaced during a typical Sunday afternoon meeting in April of 2015 discussing research and education projects with Mackinnon. After having built a substantial online educational program based on this thesis, which included an extensive library of educational videos describing anatomically precise techniques and clinical reasoning in nerve surgery – she asked, whether we could ethically display the plates with the videos and share them with nerve surgeons from around the world according to specific ethical guidelines. The development of these surgical procedures was heavily influenced by the use of the atlas from the *Shoah*, and Mackinnon still used specific anatomical plates for surgery with disclosure, respect, gratitude, and solemnity. The open-access videos have been viewed more than 4 million times across the world including regions of strife and war. Nerve surgery is an essential specialty for restoring function to patients injured by trauma and conflict (see **Appendix**, letter from Vinnytsia Regional Neurological Hospital).

200805 YEE PHD THESIS v5.indd 151

plates from the atlas to accompany our videos as representations of important anatomical landmarks and nerve branches, crucial to the description of the procedure in these surgical videos. Recreating the plates to match the same level of accuracy also raised ethical concerns – would the produced materials be simply a recreation of the abuse suffered by the victims of the Holocaust? Serendipitously (*bashert*), in that very week, Sabine Hildebrandt, an anatomy educator and historian of anatomy at Harvard Medical School, presented the 2015 *Yom Hashoah* lecture at our institution.^{86,87} With trepidation, at the conclusion of her lecture, we approached Hildebrandt for her thoughts on the question of whether to “use or not to use.” Her response was that good might come from iniquity and crime, but with disclosure of its history and deliberation with the experts, and this became the start of a multi-disciplinary collaboration of individuals to lead an ethics inquiry.

Encouraged with the guidance of Hildebrandt and William Seidelman, who supported the historically aware atlas use to treat patients with complex nerve injuries, we moved forward with developing our sophisticated video-based learning platform (*PASSIO* – Latin for *suffering and enduring*; now *Learn Surgery* – learnsurgery.wustl.edu) to equitably educate surgeons and plans to include the history of the atlas and relevant anatomical plates. Within the first two years of *PASSIO*'s launch, we found a membership of over 1,500 surgeons from all corners of the world with diverse racial, gender, language, and training backgrounds (**Chapter 2**). These individuals would become a voice of opinion when we surveyed them on the question of whether “to use or not to use” the atlas in nerve surgery and education (**Chapter 5**). Of those who responded, over half were aware of the atlas and 13% were currently using it in surgery. We then presented a four-point proposal for the appropriate disclosure, bioethics and religious (*Halakha* – Jewish law) considerations, and remembrance, and the response were astounding. Of the respondents who were initially “undecided” (17%) or “uncomfortable” (15%) in using the atlas, a majority (76%) became comfortable with its use. Additionally, surgeons indicated in all circumstances that the atlas provided greater anatomical detail and surgical utility when compared to the well-known Netter atlas.

While these findings laid the groundwork, the considerations of bioethics and religious guidelines to acknowledge the atlas remained. A framework in applied ethics created by Ira Kodner and Doug Brown to guide patients and surgeons through shared decision making and living a code of truth and trust.⁸⁸ Also, the American College of Surgeons and the journal *Surgery* co-sponsored quarterly case studies (2008-2019) examining bioethical dilemmas using a four-option framework to navigate complicated ethical issues.³¹ Both these advancements in bioethics became relevant to us, when inquiries at the current holder of the copyright (*Elsevier*), on our use of the atlas' images for the advancement of education and medical ethics, led to the following official response: “Elsevier upholds the highest ethical and business standards. For this reason, we no longer publish Pernkopf or allow license thereof,” because “allegations arose that the bodies used for dissection to draw the images came from Holocaust victims.”^{89,90} We thus posed the question to Rabbi Joseph Polak, who has expertise in Jewish medical ethics and is a child survivor of the Holocaust,⁹¹ and Holocaust scholar Michael Grodin on whether it was ethical

from the victims' point of view to use the images of the atlas. Rabbi Polak's answer was framed in the form of a responsum – a scholarly legal and ethical response to a question posed to the Rabbi – called the *Vienna Protocol*, a set of guidelines to follow when Jewish or possibly-Jewish human remains are discovered, including a paragraph specific to the use of the atlas.^{32,33} This simple action of asking the Rabbi was considered a profound step towards addressing the atrocities committed by physicians during the Holocaust.

Based on the authority of the *Vienna Protocol*, a clinical case study was published in **Chapter 6** that lays the historical and ethical framework for questions concerning the use of the atlas in the management of anatomically complex and difficult surgical cases, with special attention to implications for medical ethics drawn from Jewish law. At the center of our work is the principle of *pikuach nefesh*, the "saving of human life," which includes the use of the atlas's images under the condition of "making it known to one and all just exactly what these drawings are [so that] the dead are accorded at least some of the dignity to which they are entitled."³² The case study presented a four-option framework of applied ethics to consider the use of the atlas when it could significantly help surgeons in the care of their patients. This includes (1) recognizing a need to take a timeout and recollect thoughts to reassess planning when encountering intraoperative difficulty, (2) calling a colleague for emergency consultation, (3) consulting ethical anatomical resources, and if required, (4) consulting the atlas with respect, gratitude, and solemnity. Furthermore, the decision by the editors of *Surgery* to publish reviewers' questions and our responses for the purpose of transparency, illustrated the continuing controversy around the question of how to treat scientific work from Nazi Germany that is part of the general canon of medical knowledge.⁹² In his commentary, Arthur Caplan made a strong moral case for the use of "tainted" information "if, at the same time, nonmaleficence can be achieved and the physician acknowledges and discloses the immoral origins of the work, in a manner that honors the victims but not its perpetrators."⁹³ Furthermore, in the second commentary by Müller et al, the Medical University of Vienna will be completing its renovation of the *Josephinum* medical museum and display a new permanent exhibition for the remembrance of medical victims of the Holocaust.⁹⁴

As we continue to assess surgeons' opinions and share these bioethical and religious considerations, there is a continued need to bring humanism into healthcare, and incorporate the voice and opinions of patients – in the consent and use of the atlas in their care.⁸⁴ In rare instances where the atlas is being used during clinical consultations with patients, surgeons can disclose its history and obtain verbal consents from patients to include the atlas in their care. In our experience thus far, we have yet to encounter any hesitation, but only deep reflection and gratitude from patients and their families when it is used to explain their complex nerve pathology. Just recently, a patient shared her personal account in clinic with Mackinnon (Fig. 7.4):

FIGURE 7.4. Patient consultation and consent of Pernkopf's atlas in the clinic. Dr. Mackinnon with a patient in the clinic discussing the patient's complex nerve pathology with the patient and her husband, who is a physician. Seen above is Netter's atlas which makes the problem appear "simple," compared to the accurate portrayal of the pathology in the atlas derived from the Holocaust (*Shoah*).

FIGURE 7.5. Whiteboard explanation of triple bypass surgery. A series of "black squiggly lines" by a cardiologist to depict a triple bypass surgery.

My husband, a professor of gastroenterology, and I were very appreciative of Dr. Mackinnon's time, expertise, and patience explaining my nerve injury. During my appointment, Dr. Mackinnon used the Pernkopf atlas to illustrate the nerves which could be affected that are causing my symptoms. Before opening the atlas, she respectfully disclosed its origins and we both agreed to view the diagrams.

Upon further discussion and acknowledging the atrocities of the Holocaust, I offered my thoughts on the use of the atlas in the medical profession as a Conservative Jew. The atlas with all its detailed diagrams exists, holding valuable information that could help countless number of people worldwide. There is nothing that is going to bring the victims of the Shoah back. Maybe there is a tiny sliver of good in all that suffering. Repairing the world, tikkun olam, is a basic tenant in Judaism. If the atlas could help teach the healers and help alleviate pain and suffering with the knowledge it holds, what sense would it make to keep it locked away, as long as there remains dignity with its use and reverence to its victims.

In contrast, a little over two years ago, my husband required triple bypass surgery. After the cardiac catheterization, his cardiologist drew a series of black squiggly lines on a white board in a consultation room indicating the blockages - lines that meant absolutely nothing to me (Fig. 7.5). Here, my husband was going to have his chest cracked open and all I got were meaningless lines as an explanation of his condition.

While our family didn't have any known close relatives remaining in Europe during the Holocaust, I believe there was extended family that stayed behind when my great grandparents immigrated to the United States at the turn of the last century who were affected, according to stories I've heard from my father. My son-in-law's maternal grandparents and great aunts and uncles survived the camps and lost their families in the Holocaust. They were too traumatized to talk about it.

Even though I don't have direct known relatives murdered in the Shoah, as a Jew it affects me greatly. The Jewish people are known as "the People of the Book" – studying the Torah, learning, and interpreting Jewish law is very important to us. We question things and try to see things in different perspectives. We try to help others, to repair the world. I always think, how many brilliant minds, artistic minds, were lost? Would we have cures for diseases or magnificent works of art?

THE ROLE OF DISSEMINATION AND IMPLEMENTATION OF INNOVATION

In general, key approaches in D&I science involve (1) an evidence-based intervention to be scaled or introduced to a new patient population, (2) planned strategies for dissemination and implementation of the intervention, (3) validated approaches to evaluate the implementation of the intervention, and (4) practices to ensure its sustainability.⁹⁵ Here, these approaches are examined in the context of the thesis.

Surgical innovations and novel interventions that are introduced to new patient populations should meet the rigor of evidenced-based medicine.⁹⁶ To depict the quality of this clinical research to its readership, peer-reviewed journals often classify therapeutic studies according to 5 levels of evidence – case report, case series, retrospective review, prospective trial, and randomized controlled trial.⁹⁷ The IDEAL framework incorporates these levels of evidence as staged pathways to develop and assess innovation in surgery.⁹⁸ Evidence-based interventions have specific origins in basic science, clinical research, and translational studies which apply benchtop research into clinical practice. It is estimated that it takes 17 years for just 14% of medical research to translate from benchtop to bedside and influence patient care.⁹⁹ In **Chapter 2**, an effective educational model was described to translate benchtop research into clinical practice and disseminate and implement these innovations in nerve surgery, which can be specifically observed through the history and development of the supercharge end-to-side (SETS) nerve transfer.

The SETS nerve transfer, originally known as the reverse end-to-side (RETS), is known as the proximal end of a donor nerve being coaptated to the side of a recipient nerve to facilitate axonal regeneration through a perineural window in an end-to-side fashion. The idea of the RETS neurotization was first described by Issacs et al in a rodent model in 2005, where they demonstrated reinnervation of a denervated muscle without a statistical difference between their experimental and control groups.¹⁰⁰ Fujiwara et al became a *first adopter* within basic science to indicate functional recovery of the denervated target organs using the RETS nerve transfer.¹⁰¹ In Issacs' second study, which was presented at the American Society for Peripheral Nerve (ASPN), the RETS nerve transfer was performed in a cut and nerve repair rodent model, and this time, achieved significant reinnervation and functional recovery.¹⁰² Our group also became *first adopters* by replicating this study in our rodent model with the additions of fluorescence imaging and histomorphometry, however more importantly were the first to translate this research into clinical practice by presenting a case report that described excellent recovery of intrinsic hand function following the anterior interosseous to ulnar motor RETS nerve transfer for an incomplete ulnar nerve injury.¹⁰³ Indeed, this study included my first-ever produced surgical video in 2009. Due to the journal's guidelines for authors to restrict video size to under 50 megabytes, this required the video to be compressed to a low resolution of 854x480, which significantly degrades the image quality. Therefore, we co-published the video on *YouTube* to retain its original 1280x720 resolution to illustrate and actively disseminate this new technique exhibiting level V evidence.

We renamed the RETS nerve transfer to the SETS nerve transfer, to reduce confusion with the end-to-side nomenclature associated with nerve transfers, in a basic science study evaluating this technique in a nerve graft rodent model.¹⁰⁴ Our clinical experience (level IV evidence) performing the SETS nerve transfer in 55 patients was published in 2015, and included a high-definition 1080p instructional surgical video. In the following years, several surgical groups became *first adopters* of this technique with publications in both basic science and clinical research.^{105,106} A recent systematic review identified 78 patients with the vast majority (92%) recovering intrinsic ulnar nerve function.¹⁰⁷ This review described the natural diffusion of the SETS nerve transfer to its *first adopters*, however, under reports its adoption especially for surgeons in private practice who rarely publish outcomes and contribute to the academic literature. The discussion around the appropriate indications for this procedure on community surgical forums prompted our investigations to revise the classifications for cubital tunnel syndrome to include CMAP amplitude,^{65,66} and refine its indications.²⁸ This led us to create an educational video-based module, as described in **Chapter 4**, to teach clinical reasoning and indications for the SETS nerve transfer for severe cubital tunnel syndrome and improve its adoption and implementation into clinical practice. Remarkably, among 41% of surgeons who were not initially interested in the SETS nerve transfer, 78% indicated that they would consider adding this procedure to their practice after completing this module. As previously described in our 2011 study comparing end-to-end (ETE) and SETS nerve coaptations, histomorphometry indicated equal number of myelinated nerve fibers (3127 vs. 2941, respectively) at the distal nerve stump.¹⁰³ This laboratory finding, coupled with a recent prospective observational study examining the SETS nerve transfer by an Egyptian nerve group,¹⁰⁸ have shifted our traditional management from ETE to SETS for proximal ulnar nerve injuries and all situations where there remains the possibility for some native nerve recovery in the future. Considering paradigms in nerve surgery,¹⁰⁹ there may be time in the future where the paradigm of nerve transfers is replaced by SETS nerve transfers.

Our video-based learning program played a significant role in the planned and active D&I of evidenced-based interventions, such as the SETS nerve transfer. However, previous to the program, there was yet to exist a validated educational approach to evaluate the active implementation of surgical innovations. Much of our international success derived from *YouTube* and its integration with Google's search engine to provide easy access to the fingertips and the pockets of people through mobile devices. Google web search had a special longitudinal section dedicated to videos and weighed these pages higher due to increased user engagement. While *YouTube* provided broad learning analytics of our international audience, the true demographics of these individuals were unknown and whether viewers were either patients or surgeons. Therefore, *PASSIO* was developed as a learning platform and use *YouTube* to carefully channel viewers to register as users on *PASSIO*. Within its first two years of launch, over 1,500 surgeons registered from all corners of the world with diverse racial, gender, language, and training backgrounds as described in **Chapter 2**. Of these registered users, 43% were active learners at least once a month. The demographics of the registered users closely resemble the viewership from *YouTube*. With an affirmed membership of surgeons, e-mail campaigns (49%

opens, 12% clicks) were distributed and included surveys to receive feedback and invitations to educational studies. In summary, our combined work in D&I became a validated educational framework to implement evidence-based interventions (benchtop to bedside) by using *YouTube* for audience outreach and a surgeon-focused platform to maximize learning.

A common criticism to sharing expertise through videos is routed in the business of having a medical practice: "Why teach others when they can send a patient to me?" While this argument intuitively make sense to individuals building a practice in surgery, our educational framework focuses on sharing expertise of individuals with established practices with decades of experience. A quote by Louis Pasteur describes the pleasure of sharing knowledge, "to him who devotes his life to science, nothing can give more happiness than increasing the number of discoveries, but his cup of joy is full when the results of his studies immediately find practical applications."¹¹⁰ A more applicable and direct quote about the importance of training in surgery is one made by G. Alexander Patterson, "If you are the only one who can do it, it is like it never happened." As suggested by Thomas Kuhn on paradigm shifts during scientific revolutions,¹¹¹ it is moral and human nature to pass knowledge to the next generation of people to carry the field forward.

ENSURING THE SUSTAINABILITY OF VIDEO-BASED LEARNING

The fourth key approach in D&I science is to ensure the sustainability of an evidence-based intervention concurrent with our video-based learning program,⁹⁵ whether that is to (1) examine current business models and trends in the media and publishing sector, (2) build an online and digital platform that meets the demands of both educators and learners, and (3) demonstrate value to key stakeholders at academic institutions and industry partners.

During the last decade, there has been a large influx of online education and video platforms in surgery that capitalized on a market to host and share content. These platforms were largely held by private organizations with origins from information technology and venture capital, each having a unique approach and business strategy to deliver educational and marketing content to surgeons. Many of these video platforms, like *VuMedi* (vumedi.com) – a video education network with a focus in orthopedic surgery, provided free and open-access videos with sharing features in exchange for industry support from medical device companies. In general, these platforms can be effective forums to discuss and market products while training surgeons. Other video platforms, like *Csurgeries* (csurgeries.com), adapted a traditional scientific publishing model to grant access through institutional and organizational subscriptions. Submitted content underwent peer-review before being assigned a digital object identifier (DOI) and sent through normal publishing channels. Specific author guidelines included only submitting key video points and restricting duration, "videos should be less than five minutes, preferably less than three minutes." *Journal of Medical Insight* (*JoMI*, jomi.com) took a similar approach except without

restrictions on video duration and published entire surgeries with live operative commentary. Interestingly, *JoMI* originated from a successful video-based scientific journal called *Journal of Visualized Experiments* (JoVE, jove.com). *GIBLIB* (giblib.com), a Los Angeles-based startup company, took a more radical and creative approach to pitch their platform as the “Netflix of Medical Education” and raised over \$2.5 million of seed capital to bolster their virtual reality and 4K streaming service. Their competitive advantage was the inclusion of professional videography team to film and produce educational videos in surgery with an emphasis on image quality. Professional societies in surgery have also invested in online education by developing unique video portals for their memberships. Of these portals, the American Society for Surgery of the Hand (ASSH) *Hand.e* is considered one of the most technologically advanced by having a committed editorial board to promote compelling high-quality content. Many of these private organizations operated with the freedom and flexibility to pivot their technology and develop new business models quickly without the multi-faceted administrative approvals required when operating within the boundaries of an academic institution. Despite having worked with several of these organizations over the last decade, the feature that was needed the most was learning analytics – the capability to understand how our videos were being digested by surgeons in order for us to develop high-standards in production quality and create user environments that foster learning.

PASSIO Education (*PASSIO*, passioeducation.com) was a video-based learning platform that was developed with avid support from the Skandalaris Center of Washington University in St. Louis. It was designed with principles of sustainability and agile software development to create a low-cost minimal viable product that specifically accommodated the needs of both learners and educators. Our surgical videos and platform were technically optimized to be indexed as the top search result with only the title of the procedure and the last name of the senior author (Fig. 7.6). One of our design principles was to provide easy access to our videos within a “click” or under the “three-click rule” of website design. A key feature required for educational research was learning analytics.⁴² Several enterprise-level video services were examined, and the service which excelled in Gartner’s magic quadrant of business intelligence (the service’s ability to execute and complete its vision) was used. Our video service partner also allowed for the customization of the learning analytics and include third-party application programming interface (API) access, which granted us the ability to develop rich features like an interactive chaptering (table-of-contents) system (Fig. 7.7). For example, this system specifically interacted with the video to describe its presented content and timepoint to help construct a cognitive schema to the learner. Furthermore, upload and suggestion systems for learners were being developed to encourage submissions and produce expert content by educators. We could inspire surgeon educators to generate their own expert instructional videos as an enjoyable and effective learning activity.¹¹²

While some well-known technology applications aim to retain users for as long as possible, our design philosophy was to immerse the learner with a video experience that spent the least amount of time learning, while maximizing the educational value of the displayed content. Being considerate and efficient with surgeons’ time

Surgical Procedures

➤ Mini-Laparoscopic Cholecystectomy with Intraoperative Cholangiogram for Symptomatic Cholelithiasis (Gallstones)

Brunt LM¹ Singh R¹, Yee A²

September 26, 2017

Minimal invasive laparoscopic cholecystectomy is the typical surgical treatment for cholelithiasis (gallstones), where patients present with a history of upper abdominal pain and episodes of biliary colic. The classic technique for minimal invasive laparoscopic cholecystectomy involves four ports: o... [\[Read more\]](#)

➤ Superficial Radial Sensory Nerve Release with Tenotomy of the Brachioradialis Tendon

Mackinnon SE¹ Yee A¹

February 5, 2017

The superficial radial sensory nerve can be entrapped between the brachioradialis and extensor carpi radialis longus tendons as the radial sensory nerve courses superficially from its deep origin. Compression of the radial sensory nerve presents with numbness and/or pain on the dorsal radial aspect ... [\[Read more\]](#)

➤ Common Peroneal Nerve Release at the Fibular Head

Mackinnon SE¹ Yee A¹

November 3, 2016

Entrapment of the common peroneal nerve (CPN) at the fibular head is an under-recognized lower extremity neuropathy that contributes to weakness of the musculature within the anterior and lateral compartments of the leg and progress to foot drop. As well, there can be numbness/pain within the territ... [\[Read more\]](#)

➤ Superficial Peroneal Nerve Release in the Lower Leg

Mackinnon SE¹ Yee A¹

October 9, 2016

Compression of the superficial peroneal nerve (SPN) is due to the superficial fascial layer that encapsulates the SPN and its distal entrapment point called the transverse crural ligament. These structures are typically the cause for numbness and pain in the territory of the SPN. Release of the SPN ... [\[Read more\]](#)

➤ Revision Ulnar Nerve Transposition Following Failed Submuscular Ulnar Nerve Transposition

Mackinnon SE¹ Yee A¹

August 30, 2016

Failed surgical management of cubital tunnel syndrome may warrant a revision ulnar nerve transposition. Revision surgery is associated with increased technical difficulty depending on the primary procedure. The senior author's preferred technique for management of cubital tunnel syndrome is a trans... [\[Read more\]](#)

FIGURE 7.6. PASSIO surgical procedures section. This section of PASSIO included a series of surgical procedures that were sorted by “most recent” and displayed a thumbnail, title, authors, authors’ affiliation, date, abstract, favorites, and comments.

Tracheotomy and endotracheal intubation continues to be most common cause for tracheal stenosis and management involves tracheal resection and reapproximation. In this case, the patient presented with a history of multiple cardiac surgical procedures. She undergone a tracheostomy and developed recent symptoms of stridor. Imaging studies demonstrated a typical tracheostomy and stromal stricture. Surgical management involved tracheal resection and primary anastomosis. This video details the specifics for a tracheal resection from incision to closure.

Standard Edition

7

Table of Contents

[00:00:00](#) - Introduction

[00:00:20](#) - Incision

[00:00:28](#) - Superficial Dissection to Elevate Subplatysmal Flaps

[00:01:26](#) - Subplatysmal Dissection

[00:02:48](#) - Dividing the Infrahyoid Muscles along the Midline

[00:03:21](#) - Dividing the Thyroid Isthmus

[00:03:35](#) - Identifying the Tracheal Stricture and Mobilizing Away from Tracheal Wall

[00:03:54](#) - Finger Dissection along the Trachea

[00:04:06](#) - Anterior Traction Suture and Exam of Tracheal Stricture and Adjacent Landmarks

[00:04:25](#) - Partial Incision Proximal to the Stricture

[00:04:51](#) - Anterior Traction Sutures on the Proximal Airway and Stricture

FIGURE 7.7. Interactive chaptering system. To make it more efficient for learners to browse the video, an interactive chaptering system was created with surgical steps and their respective timecodes. As the video played, the respective surgical step is highlighted. Displayed is the short-format video for a tracheal resection of a stomal stricture and repair. Web pages were optimized for PC, tablets, and mobile devices.

may have explained our success and popularity. Direct API access provided us the ability to customize and implement a video player to display viewing engagement along the timeline, highlight important areas of the video using an interactive chaptering system, and create “visual cards” to overlay and describe additional information, amongst other common features such as variable playback speed, video quality, and closed captioning. The visual cards and chaptering system were also designed to become areas for potential industry-sponsored education. For example, these areas would highlight and emphasize products being used by master surgeons, and channel interested users to specific product pages for more information.

With respect to industry-sponsored education as a traditional model of sustainability, our approach was to leverage the expertise of master surgeons to depict their non-bias use of products and free from industry influence, to maximize the value generated from sponsorship. This strategy was one of many planned to demonstrate a hybrid B2C-B2B model and significant user traction on a timeline of tiered deliverables for raising external capital and funding. Nonetheless, in the early half of 2019, *PASSIO* underwent migration to Washington University *Learn Surgery* (learn-surgery.wustl.edu) to take advantage of university resources authorized by business associate agreements. The migration required us revise our approach to ensure the program’s sustainability with the following key points and value propositions that align with academic institutions:

1. Fulfilling the university’s intrinsic mission for education and innovation in healthcare.
2. Providing global exposure to the premiere medical center and its master surgeons.
3. Generating international interest for surgeons, patient, and visitors for scholarly and healthcare opportunities.
4. Standardizing quality-of-care in countries with established healthcare systems and for those in-need.
5. Creating a channel for the dissemination and implementation of surgical innovations.
6. Providing unique development and legacy opportunities for surgical alumnus.
7. Contribute to the evolving and desired entrepreneurial culture in healthcare and information technology.

FUTURE PERSPECTIVES

A new and emerging approach that compliments video-based learning is surgical coaching (Fig. 7.8). This is defined as providing individualized and constructive feedback for performance improvement.^{50,51} Within Ericsson's gradual sequence of states, the third mental representation for attaining expertise is receiving feedback on performance.⁶ Several studies examining example-based learning through the perspectives of cognitive and social-cognitive research have incorporated feedback as a vital intervention to enhance student performance.⁶⁸ In surgery, videos of operative performance can be the basis of coaching activities through synchronized sessions, where a coach and a learner review performance together at the same time, or asynchronized sessions, where a learner submits materials for a coach to review and provide feedback at a later time.¹¹³

Video-based coaching has complemented operative room teaching by having more "teaching points," per unit of time to work through complex decision-making, when compared to intraoperative teaching.¹¹⁴ These coaching activities can also be a rich source of data and quantitative evidence to examine the efficiency of our video-based learning program. For example, surgeons can submit videos or even photos of their surgeries for expert review after learning directly from our videos (Fig. 7.9). Naturally, the expert surgeons who participated in the creation of our educational program by producing content can become certified coaches using established coaching frameworks to facilitate expert-to-peer sessions. This serves two purposes: (1) to assure safe adoption and implementation of surgical innovation and (2) identify deficits in our educational interventions to improve upon.

In a very early questionnaire assessing interest in video-based surgical coaching in our *Learn Surgery* membership, 55 surgeons immediately responded. Among these respondents, (77% practicing with median 18 years [range 1-36] of experience, 19% trainees; 56% originated outside the U.S., most expressed interest in expert-to-peer coaching for technical (82%) and clinical (65%) skills. Overall, 78% would like coaching to be incorporated into continuing medical education (CME) and maintenance of certification. Over half (56%) did not have video capabilities in the operating room, although 84% would be comfortable with mounting a camera and 92% considered themselves as technological capable. All agreed that ensuring patient privacy and clear medicolegal guidance are important factors to coaching. These findings demonstrate early interest in surgical coaching for continuing professional development (CPD), however, technical support for video capture is needed.¹¹⁵ Once the appropriate medicolegal guidelines are defined, to assure patient privacy and protected channels for sharing compliant data across institutions for quality improvement and patient safety purposes, the integration of video-based coaching with video-based learning has the potential to become the new model for CME and CPD. For example, the non-profit organization, *Academy for Surgical Coaching* (surgicalcoaching.org), has a certification program for surgeons to become qualified coaches and technology that can facilitate online expert-to-peer coaching sessions.

FIGURE 7.8. New model for continuing professional development (CPD). The implementation of video-based learning and coaching will create a robust model of CPD through distant learning. Having established an educational program using expert videos to teach clinical reasoning, operative techniques, and post-operative therapy, video-based coaching activities (asynchronized or synchronized sessions) can provide a rich source of data as quantitative feedback and implementation evidence. This new model of CPD can be integrated with continuing medical education and maintenance of certification in surgery.

FIGURE 7.9. Surgical feedback and coaching using photos. Photos can be a valuable source of data to provide expert feedback and coaching to improve performance. A surgeon submitted photos (left) to receive feedback after using our videos to perform a common peroneal nerve release at the fibular head on the left leg. Upon observing their photos, expert feedback was given with questions regarding the intact intermuscular septums circled in yellow. The surgeon responded that these septums were released following the photos, illustrating a need to develop guidelines for submitting photos as surgical steps. Photos (right) of surgeries after receiving expert video-based learning and coaching could illustrate performance improvement and be evidence of implementation. For example, in this photo, an intermuscular septum was depicted as being released (white arrow).

7

Major improvements of computer technology, specifically graphical processing units, and the access to big data have caused a resurgence of interest in neural networks and machine learning. This has led to significant recent advances in artificial intelligence (AI) in both society and healthcare.^{116,117} Computer vision, or the use of AI and algorithms to distinguish patterns from images, has achieved better diagnostic sensitivity and specificity than radiologists in lung cancer screening.¹¹⁸ Hashimoto et al have also used computer vision in surgery to analyze intraoperative videos to recognize operative steps in laparoscopic sleeve gastrectomy.¹¹⁹ This study described the tremendous broad application in the development of expertise and video-based learning and coaching. For example, if implemented correctly, automated analysis of surgeries could help identify operative deficits to improve upon and also facilitate review in coaching activities. This technology could also be used to improve the production workflow in creating instructional surgical videos by identifying and removing non-relevant or poor-quality video frames. Additionally, our production workflow could be automated to use computer vision to create short surgical videos, similar to how Netflix created movie trailers using AI and 20th Century Fox used AI to analyze movie trailers to determine what film audiences will like.¹²⁰⁻¹²² Computer vision has a large potential to contribute significantly to quality improvement and education in surgery.

Since the recent 2019 Holocaust Education Week in Toronto where our collaborative group presented a special symposium on the Pernkopf atlas,¹²³ several recommendations were made to further advance the ethics controversy. Leila Lax, a professor in the Masters of Science program in Biomedical Communications, at the Faculty of Medicine, University of Toronto, organized this symposium and identified a need to incorporate the opinions from the perspectives of medical illustrators, as well as a further call to action to improve informed use of the Pernkopf atlas.¹²⁴ The last essay from this profession was David Williams, whose detailed interviews of the surviving Pernkopf's illustrators, exposed the 'evil' origin of the atlas.¹⁶ The framework used to assess the atlas in surgical practice in **Chapter 5**, could be easily adapted for medical illustrators, which would not only raise awareness and bring another profession into the fold, but also provide an opportunity to discuss the techniques used by Pernkopf's illustrators for a philosophical discussion on a major anatomical project. While we have reported one Jewish perspective from a patient, there is also a significant need to incorporate the voices of patients in the ethical consideration and use of the atlas in their care. Effective communication between surgeon and patient is a central clinical function that can require a surgeon to illustrate a complex pathology,¹²⁵ which may involve the atlas especially for procedures that requires its use in the operating room. More research on patient views and informed consent will provide insights to bring humanism into healthcare. Additionally, the original Pernkopf watercolours are currently under the custody of Elsevier. To provide a space of learning about the history of the medical atrocities, as well as to allow a dignified memorialization of the victims, these paintings could be donated to the respective Holocaust memorials and museums or repatriated by the Medical University of Vienna for remembrance.⁹⁴ As result, a proper committee could be formed to address its ethical handling and license requests, perhaps to contribute the anatomical plates to an online educational program using, for example, our videos to educate surgeons on its history and bioethical and religious considerations. This combined work honors the victims of the atlas by accurately retelling their history through the continued work on ethical guidelines, and forever being a reminder of the destructive forces that reside in scientific medicine and its practitioners.^{32,126}

REFERENCES

1. Brownson RC, Colditz GA, Proctor EK. *Dissemination and Implementation research in Health: Translating Science to Practice*. New York, NY: Oxford University Press; 2018.
2. Marcus RK, Lillemoe HA, Caudle AS, et al. Facilitation of Surgical Innovation: Is It Possible to Speed the Introduction of New Technology While Simultaneously Improving Patient Safety? *Ann Surg*. 2019.
3. Milat AJ, Li B. Narrative review of frameworks for translating research evidence into policy and practice. *Public Health Res Pract*. 2017;27(1).
4. Hirst A, Philippou Y, Blazeby J, et al. No Surgical Innovation Without Evaluation: Evolution and Further Development of the IDEAL Framework and Recommendations. *Ann Surg*. 2018.
5. Berwick DM. Disseminating innovations in health care. *JAMA*. 2003;289(15):1969-1975.
6. Ericsson KA. Acquisition and maintenance of medical expertise: a perspective from the expert-performance approach with deliberate practice. *Acad Med*. 2015;90(11):1471-1486.
7. Birkmeyer JD, Finks JF, O'Reilly A, et al. Surgical skill and complication rates after bariatric surgery. *N Engl J Med*. 2013;369(15):1434-1442.
8. Mackinnon SE. Discussion: State-of-the-Art Techniques in Treating Peripheral Nerve Injury. *Plast Reconstr Surg*. 2018;141(3):711-712.
9. Mackinnon SE. Future Perspectives in the Management of Nerve Injuries. *J Reconstr Microsurg*. 2018;34(9):672-674.
10. Dimick JB, Scott JW. A Video Is Worth a Thousand Operative Notes. *JAMA Surg*. 2019.
11. Angelos P. The ethical challenges of surgical innovation for patient care. *Lancet*. 2010;376(9746):1046-1047.
12. Barnes RW, Lang NP, Whiteside MF. Halstedian technique revisited. Innovations in teaching surgical skills. *Ann Surg*. 1989;210(1):118-121.
13. Hildebrandt S, Seidelman WE. Where do they come from? A call for complete transparency regarding the origin of human tissues in research. *ESMO Open*. 2017;2(2):e000201.
14. Akademischer Senat der Universität Wien. Senatsprojekt der Universität Wien: Untersuchungen zur Anatomischen Wissenschaft in Wien 1938–1945. (Unpublished Manuscript). In: Akademischer Senat der Universität Wien.; 1998.
15. Weissmann G. Springtime for Pernkopf. *Hosp Pract (Off Ed)*. 1985;20(10):142-168.
16. Williams DJ. The history of Eduard Pernkopf's *Topographische Anatomie des Menschen*. *J Biocommun*. 1988;15(2):2-12.
17. Ericsson KA. Necessity is the mother of invention: video recording firsthand perspectives of critical medical procedures to make simulated training more effective. *Acad Med*. 2014;89(1):17-20.
18. Prober CG, Khan S. Medical education reimagined: a call to action. *Acad Med*. 2013;88(10):1407-1410.
19. Ritter EM. Invited Editorial LAP-VEGaS Practice Guidelines for Video-based Education in Surgery: Content is Just the Beginning. *Ann Surg*. 2018. [Published online ahead of print].
20. Mackinnon SE, Novak CB. Compression Neuropathies. In: *Green's Operative Hand Surgery*. Vol Volume 1. Churchill Livingstone; 2017.
21. Martin JA, Regehr G, Reznick R, et al. Objective structured assessment of technical skill (OSATS) for surgical residents. *Br J Surg*. 1997;84(2):273-278.
22. Van Heest A, Putnam M, Agel J, Shanedling J, McPherson S, Schmitz C. Assessment of technical skills of orthopaedic surgery residents performing open carpal tunnel release surgery. *J Bone Joint Surg Am*. 2009;91(12):2811-2817.
23. Yee A, Padovano WM, Patterson JMM, et al. Effectiveness of Video-Based Learning in Teaching Clinical Reasoning for Cubital Tunnel Surgeries. *Ann Surg*. 2019;Submitted.
24. Yavner SD, Pusic MV, Kalet AL, et al. Twelve tips for improving the effectiveness of web-based multimedia instruction for clinical learners. *Med Teach*. 2015;37(3):239-244.
25. Yue C, Kim J, Ogawa R, Stark E, Kim S. Applying the cognitive theory of multimedia learning: an analysis of medical animations. *Med Educ*. 2013;47(4):375-387.
26. Daley BJ, Torre DM. Concept maps in medical education: an analytical literature review. *Med Educ*. 2010;44(5):440-448.
27. Moulton ST, Turkay S, Kosslyn SM. Does a presentation's medium affect its message? PowerPoint, Prezi, and oral presentations. *PLoS One*. 2017;12(7):e0178774.
28. Power HA, Kahn LC, Patterson JMM, Yee A, Moore AM, Mackinnon SE. Refining indications

- for the supercharge end-to-side anterior interosseous to ulnar motor nerve transfer in cubital tunnel syndrome. *Plast Reconstr Surg*. 2019;In-press.
29. Power HA, Sharma K, El-Haj M, Moore AM, Patterson MM, Mackinnon SE. Compound Muscle Action Potential Amplitude Predicts the Severity of Cubital Tunnel Syndrome. *J Bone Joint Surg Am*. 2019;101(8):730-738.
 30. Caplan AL. *When Medicine Went Mad: Bioethics and the Holocaust*. New York NY: Springer Science & Business Media; 2012.
 31. Kodner IJ. Surgeons and clinical ethics. *Surgery*. 2008;143(4):460-462.
 32. Polak JA. "Vienna Protocol" for when Jewish or Possibly-Jewish Human Remains are Discovered. In: Seidelman WE, Elbaum L, Hildebrandt S, eds. *How to Deal with Holocaust Era Human Remains: Recommendations arising from a special symposium*. Boston, MA: Elie Wiesel Center for Jewish Studies, Boston University; 2017.
 33. Polak RA. Vienna Protocol for when Jewish or Possibly-Jewish Human Remains are Discovered. In: H. C, C. D, P. W, eds. *Medical Ethics in the 70 Years after the Nuremberg Code, 1947 to the Present (Wiener Klinische Wochenschrift)*. Vol 130 (Supplement 3).2018:S239-S243.
 34. Deal SB, Alseidi AA. Concerns of Quality and Safety in Public Domain Surgical Education Videos: An Assessment of the Critical View of Safety in Frequently Used Laparoscopic Cholecystectomy Videos. *J Am Coll Surg*. 2017;225(6):725-730.
 35. Lemon TI. Concerns about academic publishing on YouTube. *Acad Med*. 2013;88(9):1194.
 36. Pitcher GS, Newton DH, Amendola MF. Common Femoral Artery Access on YouTube: What Practices are Being Shown and Who is Delivering the Message? *J Surg Educ*. 2017;74(3):455-458.
 37. Samuel N, Alotaibi NM, Lozano AM. YouTube as a Source of Information on Neurosurgery. *World Neurosurg*. 2017.
 38. Ward B, Ward M, Nichaporuck A, Alaeddin I, Paskhover B. Assessment of YouTube as an Informative Resource on Facial Plastic Surgery Procedures. *JAMA Facial Plast Surg*. 2018. [Published online ahead of print].
 39. Celentano V, Smart N, McGrath J, et al. LAP-VEGaS Practice Guidelines for Reporting of Educational Videos in Laparoscopic Surgery: A Joint Trainers and Trainees Consensus Statement. *Ann Surg*. 2018. [Published online ahead of print].
 40. Kim J, Guo PJ, Seaton DT, Mitros P, Gajos KZ, Miller RC. Understanding in-video dropouts and interaction peaks in online lecture videos. *Proceedings of the first ACM conference on Learning @ scale conference*. 2014:31-40.
 41. Wu S, Rizoio M-A, Xie L. Beyond Views: Measuring and Predicting Engagement in Online Videos. *arXiv*. 2018:1709.02541.
 42. Lau KHV, Farooque P, Leydon G, Schwartz ML, Sadler RM, Moeller JJ. Using learning analytics to evaluate a video-based lecture series. *Med Teach*. 2018;40(1):91-98.
 43. Moulton CA, Regehr G, Lingard L, Merritt C, MacRae H. Slowing down to stay out of trouble in the operating room: remaining attentive in automaticity. *Acad Med*. 2010;85(10):1571-1577.
 44. Prince MJ, Felder RM. Inductive teaching and learning methods: definitions, comparisons, and research bases. *J Eng Educ*. 2006;95:123-138.
 45. Djulbegovic B, Hozo I, Beckstead J, Tsalatsanis A, Pauker SG. Dual processing model of medical decision-making. *BMC Med Inform Decis Mak*. 2012;12:94.
 46. Kahneman D. *Thinking, fast and slow*. New York, NY: Farrar, Straus and Giroux; 2011.
 47. Grezes J, Decety J. Functional anatomy of execution, mental simulation, observation, and verb generation of actions: a meta-analysis. *Hum Brain Mapp*. 2001;12(1):1-19.
 48. Hurley S. The shared circuits model (SCM): how control, mirroring, and simulation can enable imitation, deliberation, and mindreading. *Behav Brain Sci*. 2008;31(1):1-22; discussion 22-58.
 49. Rizzolatti G, Craighero L. The mirror-neuron system. *Annu Rev Neurosci*. 2004;27:169-192.
 50. Greenberg CC, Ghousseini HN, Pavuluri Quamme SR, Beasley HL, Wiegmann DA. Surgical coaching for individual performance improvement. *Ann Surg*. 2015;261(1):32-34.
 51. Greenberg CC, Klingensmith ME. The Continuum of Coaching: Opportunities for Surgical Improvement at All Levels. *Ann Surg*. 2015;262(2):217-219.
 52. Greenberg CC, Dombrowski J, Dimick JB. Video-Based Surgical Coaching: An Emerging Approach to Performance Improvement. *JAMA Surg*. 2016;151(3):282-283.
 53. Alotaibi NM, Ibrahim GM, Wang J, et al. Neurosurgeon academic impact is associated with clinical outcomes after clipping of ruptured intracranial aneurysms. *PLoS One*. 2017;12(7):e0181521.
 54. Jyot A, Baloul MS, Finnesgard EJ, et al. Surgery Website as a 24/7 Adjunct to a Surgical Cur-

- riculum. *J Surg Educ*. 2018;75(3):811-819.
55. Kantar RS, Alfonso AR, Ramly EP, et al. Knowledge and Skills Acquisition by Plastic Surgery Residents Through Digital Simulation Training: A Prospective Randomized Blinded Trial. *Plast Reconstr Surg*. 2019.
56. Plana NM, Rifkin WJ, Kantar RS, et al. A Prospective, Randomized, Blinded Trial Comparing Digital Simulation to Textbook for Cleft Surgery Education. *Plast Reconstr Surg*. 2019;143(1):202-209.
57. Durning SJ, Artino AR, Jr., Schuwirth L, van der Vleuten C. Clarifying assumptions to enhance our understanding and assessment of clinical reasoning. *Acad Med*. 2013;88(4):442-448.
58. Elstein AS, Schwartz A. Clinical problem solving and diagnostic decision making: selective review of the cognitive literature. *BMJ*. 2002;324(7339):729-732.
59. Elstein AS, Shulman LS, Sprafka SA. *Medical Problem Solving: an Analysis of Clinical Reasoning*. Cambridge, MA: Harvard University Press; 1978.
60. Higgs J, Jones M, Loftus S, Christensen N. *Clinical Reasoning in the Health Professions*. 3rd ed. Boston, MA: Elsevier Health Sciences; 2008.
61. Kobayashi J, Mackinnon SE, Watanabe O, et al. The effect of duration of muscle denervation on functional recovery in the rat model. *Muscle Nerve*. 1997;20(7):858-866.
62. Tang DT, Barbour JR, Davidge KM, Yee A, Mackinnon SE. Nerve entrapment: update. *Plast Reconstr Surg*. 2015;135(1):199e-215e.
63. Mayer RE. *The Cambridge Handbook of Multimedia Learning*. Cambridge University Press; 2005.
64. Topps D, Helmer J, Ellaway R. YouTube as a platform for publishing clinical skills training videos. *Acad Med*. 2013;88(2):192-197.
65. Qing C, Zhang J, Wu S, et al. Clinical classification and treatment of cubital tunnel syndrome. *Exp Ther Med*. 2014;8(5):1365-1370.
66. Watanabe M, Arita S, Hashizume H, Honda M, Nishida K, Ozaki T. Multiple regression analysis for grading and prognosis of cubital tunnel syndrome: assessment of Akahori's classification. *Acta Med Okayama*. 2013;67(1):35-44.
67. Mayer RE. Applying the science of learning: evidence-based principles for the design of multimedia instruction. *Am Psychol*. 2008;63(8):760-769.
68. van Gog T, Rummel N. Example-based learning: Integrating cognitive and social-cognitive research perspectives. *Educational Psychology Review*. 2010;22(2):155-174.
69. van Merriënboer JJ, Sweller J. Cognitive load theory in health professional education: design principles and strategies. *Med Educ*. 2010;44(1):85-93.
70. Van Gog T, Paas F, Van Merriënboer JJ, G. Effects of studying sequences of process-oriented and product-oriented worked examples on troubleshooting transfer efficiency. *Learn Instr*. 2008;18(3):211-222.
71. Kassirer JP. Teaching clinical reasoning: case-based and coached. *Acad Med*. 2010;85(7):1118-1124.
72. Atkinson RK, Derry SJ, Renkl A, Wortham D. Learning from examples: Instructional principles from the worked examples research. *Review of Educational Research*. 2000;70(2):181-214.
73. De Koning BB, Tabbers HK, Rikers RMJP, Paas F. Towards a framework for attention cueing in instructional animations: Guidelines for research and design. *Educ Psychol Rev*. 2009;21(2):113-140.
74. Kalyuga S. Expertise reversal effect and its implications for learner-tailored instruction. *Educational Psychology Review*. 2007;19(4):509-539.
75. Sweller J, Ayres PL, Kalyuga S, Chandler P. The expertise reversal effect. *Educational Psychologist*. 2003;38(1):23-31.
76. Durning S, Artino AR, Jr., Pangaro L, van der Vleuten CP, Schuwirth L. Context and clinical reasoning: understanding the perspective of the expert's voice. *Med Educ*. 2011;45(9):927-938.
77. McBee E, Ratcliffe T, Picho K, et al. Consequences of contextual factors on clinical reasoning in resident physicians. *Adv Health Sci Educ Theory Pract*. 2015;20(5):1225-1236.
78. McBee E, Ratcliffe T, Picho K, et al. Contextual factors and clinical reasoning: differences in diagnostic and therapeutic reasoning in board certified versus resident physicians. *BMC Med Educ*. 2017;17(1):211.
79. Renkl A, Atkinson RK. Structuring the transition from example study to problem solving in cognitive skill acquisition: A cognitive load perspective. *Educ Psychol*. 2003;38(1):15-22.
80. Schunk DH, Zimmerman BJ. *Motivation and Self-regulated Learning: Theory, Research, and Applications*. New York, NY: Lawrence Erlbaum Associates; 2012.

81. Cheung JJH, Kulasegaram KM, Woods NN, Moulton CA, Ringsted CV, Brydges R. Knowing How and Knowing Why: testing the effect of instruction designed for cognitive integration on procedural skills transfer. *Adv Health Sci Educ Theory Pract*. 2018;23(1):61-74.
82. Marinopoulos SS, Dorman T, Ratanawongsa N, et al. Effectiveness of continuing medical education. *Evid Rep Technol Assess (Full Rep)*. 2007(149):1-69.
83. Mackinnon SE. When medical information comes from Nazi atrocities. [Under review]. 2020.
84. Begley S. The surgeon had a dilemma only a Nazi medical text could resolve. Was it ethical to use it? *STAT*. May 30, 2019.
85. Baker K. Eduard Pernkopf: The Nazi book of anatomy still used by surgeons. *BBC*. August 19, 2019, 2019.
86. Hildebrandt S. *The Anatomy of Murder: Ethical Transgressions and Anatomical Science during the Third Reich*. New York: Berghahn Books; 2016.
87. Hildebrandt S. The Anatomy of Murder: Ethical Transgressions and Anatomical Science during the Third Reich. 2015 Yom Hashoah Lecture for Medical Grand Rounds at the Department of Medicine; April 16, 2015; Washington University School of Medicine.
88. Kodner IJ. Ethics curricula in surgery: needs and approaches. *World J Surg*. 2003;27(8):952-955; discussion 955-956.
89. Korz C. Permission Request of Pernkopf's Atlas for Education. In: Mackinnon SE, ed. E-mail: Elsevier; 2016.
90. Korz C. Permission Request of Pernkopf's Atlas for Ethics Manuscript. In: Yee A, ed. E-mail: Elsevier; 2017.
91. Polak JA. *After the Holocaust the Bells Still Ring*. Jerusalem, Israel: Urim Publications; 2015.
92. Yee A, Zubovic E, Yu J, et al. RESPONSE TO REVIEWERS. *Surgery*. 2018;165(5):868-869.
93. Caplan A. Commentary: Consulting evil. *Surgery*. 2019;165(5):870.
94. Muller M, Czech H, Druml C. Commentary: The Medical University of Vienna and the historic legacy of Pernkopf's atlas. *Surgery*. 2019;165(5):871-872.
95. Proctor E, Silmere H, Raghavan R, et al. Outcomes for implementation research: conceptual distinctions, measurement challenges, and research agenda. *Adm Policy Ment Health*. 2011;38(2):65-76.
96. Akobeng AK. Principles of evidence based medicine. *Arch Dis Child*. 2005;90(8):837-840.
97. Swanson JA, Schmitz D, Chung KC. How to practice evidence-based medicine. *Plast Reconstr Surg*. 2010;126(1):286-294.
98. Hirst A, Philippou Y, Blazeby J, et al. No Surgical Innovation Without Evaluation: Evolution and Further Development of the IDEAL Framework and Recommendations. *Ann Surg*. 2019;269(2):211-220.
99. Brownson RC, Kreuter MW, Arrington BA, True WR. Translating scientific discoveries into public health action: how can schools of public health move us forward? *Public Health Rep*. 2006;121(1):97-103.
100. Isaacs J, Allen D, Chen LE, Nunley J, 2nd. Reverse end-to-side neurotization. *J Reconstr Microsurg*. 2005;21(1):43-48; discussion 49-50.
101. Fujiwara T, Matsuda K, Kubo T, et al. Axonal supercharging technique using reverse end-to-side neurorrhaphy in peripheral nerve repair: an experimental study in the rat model. *J Neurosurg*. 2007;107(4):821-829.
102. Isaacs JE, Cheatham S, Gagnon EB, Razavi A, McDowell CL. Reverse end-to-side neurotization in a regenerating nerve. *J Reconstr Microsurg*. 2008;24(7):489-496.
103. Kale SS, Glaus SW, Yee A, et al. Reverse end-to-side nerve transfer: from animal model to clinical use. *J Hand Surg Am*. 2011;36(10):1631-1639 e1632.
104. Barbour J, Yee A, Kahn LC, Mackinnon SE. Supercharged end-to-side anterior interosseous to ulnar motor nerve transfer for intrinsic musculature reinnervation. *J Hand Surg Am*. 2012;37(10):2150-2159.
105. Nadi M, Ramachandran S, Islam A, Forden J, Guo GF, Midha R. Testing the effectiveness and the contribution of experimental supercharge (reversed) end-to-side nerve transfer. *J Neurosurg*. 2018;130(3):702-711.
106. Baltzer H, Woo A, Oh C, Moran SL. Comparison of Ulnar Intrinsic Function following Supercharge End-to-Side Anterior Interosseous-to-Ulnar Motor Nerve Transfer: A Matched Cohort Study of Proximal Ulnar Nerve Injury Patients. *Plast Reconstr Surg*. 2016;138(6):1264-1272.
107. Dunn JC, Gonzalez GA, Fernandez I, Orr JD, Polfer EM, Nesti LJ. Supercharge End-to-Side Nerve Transfer: Systematic Review. *Hand (N Y)*. 2019;1558944719836213.
108. Ghoraba SM, Mahmoud WH, Elsergany MA, Ayad HM. Ulnar nerve injuries (Sunderland grade

- V): A simplified classification system and treatment algorithm. *Plast Reconstr Surg Glob Open*. 2019;(In-press).
109. Domeshek LF, Novak CB, Patterson MM, et al. Nerve Transfers - A Paradigm Shift in the Reconstructive Ladder. *Plast Reconstr Surg Glob Open*. 2019;7(6):e2290.
 110. Brownson RC, Fielding JE, Maylahn CM. Evidence-based public health: a fundamental concept for public health practice. *Annu Rev Public Health*. 2009;30:175-201.
 111. Kuhn TS. *The Structure of Scientific Revolutions*. 3rd ed. Chicago and London: University of Chicago Press; 1996.
 112. Hoogerheide V, Visee J, Lachner A, van Gog T. Generating an instructional video as homework activity is both effective and enjoyable. *Learn Instr*. 2019;64.
 113. Hu YY, Peyre SE, Arriaga AF, et al. Postgame analysis: using video-based coaching for continuous professional development. *J Am Coll Surg*. 2012;214(1):115-124.
 114. Hu YY, Mazer LM, Yule SJ, et al. Complementing Operating Room Teaching With Video-Based Coaching. *JAMA Surg*. 2017;152(4):318-325.
 115. Saun TJ, Zuo KJ, Grantcharov TP. Video Technologies for Recording Open Surgery: A Systematic Review. *Surg Innov*. 2019;26(5):599-612.
 116. Hashimoto DA, Rosman G, Rus D, Meireles OR. Artificial Intelligence in Surgery: Promises and Perils. *Ann Surg*. 2018;268(1):70-76.
 117. Topol EJ. High-performance medicine: the convergence of human and artificial intelligence. *Nat Med*. 2019;25(1):44-56.
 118. Ardila D, Kiraly AP, Bharadwaj S, et al. End-to-end lung cancer screening with three-dimensional deep learning on low-dose chest computed tomography. *Nat Med*. 2019;25(6):954-961.
 119. Hashimoto DA, Rosman G, Witkowski ER, et al. Computer Vision Analysis of Intraoperative Video: Automated Recognition of Operative Steps in Laparoscopic Sleeve Gastrectomy. *Ann Surg*. 2019;270(3):414-421.
 120. Vincent J. 20th Century Fox is using AI to analyze movie trailers and find out what films audiences will like. *The Verge*. November 2, 2018.
 121. Hsieh CK, Campo M, Taliyan A, Nickens M, Pandya M, Espinoza JJ. Convolutional Collaborative Filter Network for Video Based Recommendation Systems. *arXiv*. 2018;1810.08189.
 122. Min S. Coming soon to Netflix: Movie trailers crafted by AI. *CBS News*. August 19, 2019.
 123. Hildebrandt S. Symposium Report: "The Vienna Protocol: Medicine's confrontation with continuing legacies of its Nazi past". 2019;(Under Review).
 124. Seidelman WE, Hildebrandt S, Mackinnon SE, et al. The Vienna Protocol: Medicine's confrontation with continuing legacies of its Nazi past. Sarah and Chaim Neuberger Holocaust Education Centre's Holocaust Education Week Program, "The Holocaust Then and Now."; Nov. 3-10, 2019; Symposium at the University of Toronto, Faculty of Medicine, Toronto, ON.
 125. Stewart MA. Effective physician-patient communication and health outcomes: a review. *Canadian Medical Association Journal*. 1995;152(9):1423.
 126. Hildebrandt S. Chapter 11 - Anatomy - On the Edge of Culture. In: *The Anatomy of Murder: Ethical Transgressions and Anatomical Science during the Third Reich*. New York: Berghahn Books; 2016:322-326.

APPENDIX

NEDERLANDSE SAMENVATTING | DUTCH SUMMARY
LETTER FROM VINNYTSIA REGIONAL NEUROLOGICAL HOSPITAL
PUBLICATION LIST
ACKNOWLEDGEMENTS | DANKWOORD
BIOGRAPHY

NEDERLANDSE SAMENVATTING | DUTCH SUMMARY

Het uitdragen en invoeren van innovaties is een essentieel en actief proces om chirurgie te promoten.^{1,2} Er bestaan diverse raamwerken, die de verschillende stadia van innovatie om kennis overdracht en onderzoek in de klinische praktijk te brengen.³ Het zogenaamde IDEAL kader wordt internationaal gebruikt om de kwaliteit van onderzoek te verbeteren en het nauwgezet beoordelen en rapporteren van resultaten van nieuwe interventies in chirurgie te benadrukken.⁴ Ondanks deze gevalideerde kaders, kan het proces van idee tot aan invoering vele decennia duren (geschat 17 jaren). Het betreft dan ook maar 14% van het medische onderzoek van petri-schaal naar de kliniek bedoeld voor het verbeteren van de patiënten zorg.⁵ Het beoordelen van de kwaliteit van een expert is een methode om het presteren te beoordelen en de stap te maken naar het niveau van expert.⁶ Individuen die de status van expert hebben in chirurgie kunnen beschouwd worden de initiatiefnemers voor deze innovatie,⁷ met name in specialismen die het goed doen in innovatie en het verbeteren van management paradigma's, bijvoorbeeld zenuwchirurgie.^{8,9} Deze zgn. expert chirurgen worden gezien als expert behandelaars, sublieme onderwijzers en coaches, die worden verwacht worden hun ervaring te delen. Om deze ervaring goed vast te leggen, is video een geschikt visueel medium om deliberate practice, het leren van operatieve vaardigheden en klinisch beredeneren te ondersteunen.¹⁰ In dit proefschrift is een video leerprogramma ontwikkeld als een stimulerend instrument voor het opdoen van ervaring en voor innovatie in zenuw chirurgie.

De ontwikkeling in ethiek rond deze ontwikkel processen is van het grootste belang voor alle snijdende vakken en vraagt een solide beoordeling van veiligheid, werkzaamheid en effectiviteit.¹¹ Grote voorstanders van ethiek in chirurgische innovaties zijn de chirurgen-opleiders, die helpen om de leercurve te verkorten voor een veilige verspreiding en overname van nieuwe technieken.¹² Vanuit een specialisme met innovatie en anatomie, hebben plastisch en reconstructief chirurgen vaak creatieve strategieën nodig om de anatomische kennis te gebruiken voor het herstel van ongewone en complexe defecten. Op dit kruispunt van chirurgie, anatomie en opleiding kunnen ethische echter vraagstukken ontstaan over de bron van de informatie en het gebruikte menselijk weefsel.¹³ Tijdens het ontwikkelen van opleidingsprogramma's om kennis over te brengen en leercurves te verkorten, kwamen we een ethisch dilemma tegen bij het gebruik van een anatomie atlas, die bekend stond om zijn exacte weergave van het zenuwstelsel voor chirurgie en onderwijs met als bron slachtoffers van het Derde Rijk. Om de slachtoffers van de medische misdrijven te erkennen, werden chirurgen om hun mening gevraagd over het voorstel voor de juiste onthulling, bio-ethiek en goddienstige overwegingen, alsmede de juiste nagedachtenis. Bovendien was een ethisch raamwerk voorgesteld aan chirurgen voor het overwegen van het gebruik van de Pernkopf atlas in chirurgie en onderwijs.

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Het doel van dit proefschrift was om een onderwijs platform te ontwikkelen om chirurgische innovaties uit te dragen en in te voeren gebruik makend van video (1) leren als methode om zich handelingen en beslissingen in de chirurgie eigen te maken. Zij zal ook (2) de bijbehorende ethische gevolgen in anatomie onderzoek behandelen.

DEEL I: ONTWIKKELING VAN VIDEO LEREN IN ZENUW CHIRURGIE

Een video van een bepaalde ingreep vormt een grote bron van visuele data en zij wordt door sommigen even sterk beschouwd als “duizend operatie aantekeningen”.¹⁰ Gebruikmakend van de benadering van Ericsson van het presteren van experts werd er een onderwijs programma ontwikkeld om video opnamen in zenuw chirurgie te stimuleren.^{6,17} Het program is in 2011 gestart en was gebouwd als compleet ontwerpproces om een op maat gemaakt en interactief video leren platform te maken en om daarbij de effectiviteit van het leerproces te beoordelen. Om de plaats te bepalen van video in het leren van een chirurgische handeling werd er:

1. Een film van een laag complexe ingreep bekeken om het technisch handelen te verbeteren
2. Een effectieve video module ontwikkeld om klinisch beredeneren te helpen en om de chirurgische video's te ondersteunen.

In **hoofdstuk 2** wordt het hele traject van het ontwikkelen alsmede de effectiviteit van video leren beschreven door het verkregen leereffect te analyseren. In 2011 werd een online onderwijs website, genaamd Nerve Surgery (nervesurgery.wustl.edu) gelanceerd. In het eerste jaar werd de website meer dan 67000 keer geopend en in de eerste twee jaar werden films meer dan 16000 keer bekeken. Om meer mensen te bereiken werd YouTube gebruikt voor de 117 zenuw films met als resultaat meer dan 3 miljoen kijkers uit meer dan 165 landen in zeven jaar. Tussen 2016 en 2018 werden deze international kijkers (69% van buiten de V.S.) in meer dan 1700 gebruikers op PASSIO (passioeducation.com), een op maat en interactief platform met ingebouwde leer analyse. Van de geregistreerde gebruikers was 43 % tenminste 1 maand actief op PASSIO. Deze analyses lieten zien, dat chirurgen 48% van het beeldmateriaal bekeken met een vastgestelde daling bij filmmateriaal met een langere duur. Desalniettemin is het belangrijker dat er een correlatie was tussen vasthouden van de aandacht en korte of lange instructive films. Bovendien gaven chirurgen de voorkeur aan langere videos bij zeldzame of complexe ingrepen in tegenspraak met de gedachte dat videos maximal 10 minuten mochten duren.^{18,19} Dit proefschrift presenteert de ontwikkeling van een online gemeenschap voor perifere zenuw chirurgie en de optimale verspreiding van zogenaamde “best practices” door gebruik te maken van YouTube om de verspreiding en introductie van platform voor snijders met als doel de maximale kennisoverdracht.

In **hoofdstuk 3** werd de rol van chirurgische videos onderzocht bij het leren van een operatieve verrichting. In deze studie werden 22 AIOS (opleidingsjaar 1-6) ge-

randomiseerd om zich voor te bereiden voor een ingreep in een cadaver lichaam. Zij werden verdeeld in twee groepen, een bestudeerde een gerenommeerd hand chirurgie boek²⁰ de andere dit boek samen met een video die een carpal tunnel operatie toonde. Zowel het hoofdstuk in het boek als mede ook de video werden door dezelfde auteurs (Mackinnon en Yee) gemaakt. Het functioneren van de AIOS werd gefilmd en door een onafhankelijk geblindeerd panel van chirurgen beoordeeld gebruik makend van de zogenaamde OSATS (objective structured assessment of technical skills) en een gemodificeerde versie van een beoordelingsschaal special ontwikkeld voor deze ingreep.^{21,22} Jongere AIOS (jaar 1-2) maakten minder operatieve fouten (median 1,3 versus 4) en waren meer zelfverzekerd in hun technisch handelen (median 75 versus 32) na het kijken van de chirurgische film. Deze studie laat zien, dat het visueel zien van een chirurgische ingreep essentieel in het leren van een nieuwe operatie aangetoond door het verminderen van fouten en het verhogen van het zelfvertrouwen. Deze studie benadrukt het belang van online leerplatforms om videos te integreren in het ingewikkelde leerproces om lacunes in het chirurgisch handelen te verkleinen.

In **hoofdstuk 4** werden de videos bekeken om te kijken of zij effectief waren bij klinisch beredeneren en beoordelen van de indicaties voor een operatie. Bovendien werd er gekeken of zij nuttig waren bij het zich eigen maken en toepassen van nieuwe ingrepen. In deze studie werd een video module gebruikt, die ontworpen was op klinisch neurofysiologische indicaties voor operaties van de cubitale tunnel, waarbij een zenuw transfer (SETS: supercharge end-to-side) werd toegevoegd.²³ Deze videos waren ontwikkeld volgens het leerprincipe van de cognitieve theorie voor multimedia leren (CTML).^{24,25} Deze videos werden gemaakt volgens het zogenaamde "whiteboard" principe met dynamische overgangen om de ruimtelijke oriëntatie van de belangrijkste ideeën.^{26,27} Er werd gekeken naar opdoen van kennis voor en na de lizing, bovendien werd gekeken hoeveel er van werd onthouden. Deze module was populair bij 279 chirurgen, die tenminste 30 minuten naar de video(s) keken. Dit versterkte ons idee, dat chirurgen wel naar videos langer 10 minuten willen kijken als de kijkervaring en de lezing zo ontworpen zijn, dat zij hierbij klinisch beredeneren leren. De tijd werd ook opgenomen om te kijken naar de kennis lacune tussen de feedback van de chirurg en de "belangrijkste reden om een SETS zenuw transfer te doen".^{28,29} De resultaten van de kennis namen met 3 punten toe (schaal van 0-10) en de kennis werd 3 maanden onthouden. Hiermee wordt aangetoond, dat een mogelijkheid is om de verandering van het chirurgisch handelen voor een langere periode alsmede de waarde van een video module om klinisch redeneren te leren.

DEEL II: AANGAANDE ANATOMIE IN CHIRURGISCHE INNOVATIES

De gedefinieerde stappen in ons video leerprogramma waren deels beïnvloed door het bestuderen van de Pernkopf atlas van de menselijke anatomie. Deze is zeker gehuld in tegenstrijdigheden door de eerdere onthullingen van de betrokkenheid van Eduard Pernkopf en zijn medisch tekenaars met de Nazi Partij (NSDAP).^{15,16} In

de jaren 90 was er een onderzoek door de commissie van het Senaat Project van de Universiteit van Wenen, die vast stelde, dat de lichamen van geëxecuteerde slachtoffers van het Nazi regime, afgebeeld in de atlas, onrechtmatig verkregen waren.¹⁴ Zonder enige twijfel heeft deze atlas de ontwikkeling van nieuwe technieken in de perifere zenuwchirurgie beïnvloed vanwege de hoge nauwkeurigheid van de afbeeldingen van het zenuwstelsel. Voor wij de toepassing in chirurgische innovatie en onderwijs kunnen overwegen, moeten wij eerst de ethische dilemma's verbonden aan het gebruik van materiaal verkregen van gruweldaden van artsen verbonden met de NSDAP tijdens de Holocaust, bekijken.

In **hoofdstuk 5**, keken wij naar de meningen van chirurgen over het gebruik van de Pernkopf atlas in chirurgie en onderwijs door gebruik te maken van een schaal met 4 punten om het ethisch handelen te beoordelen. Twee medische disciplines, zenuwchirurgie en mond kaak en aangezichtschirurgie, werden betrokken om de twee delen van de atlas (I – Hoofd hals, en II- Thorax, abdomen en extremiteiten) en de juistheid van de anatomie van het zenuwstelsel alsmede de hoofd hals anatomie te beoordelen. 364 chirurgen reacties werden verzameld: zij gaven aan, dat zij, in 54% bewust waren van de achtergrond van de atlas en in 16% de atlas ook regelmatig gebruikten. Van diegenen, die bewust waren van de achtergrond voelde 56% zich niet bezwaard om de atlas te gebruiken voor hun ingrepen. De mond kaak aangezicht chirurgen (MKA) waren meer terughoudend dan de zenuwchirurgen. Dit kan verklaard worden door de oudere leeftijd van de MKA chirurgen, maar ook door de kenmerken van het gezicht van de slachtoffers. Op een schaal van 4 punten, voor openbaarmaking, ethiek, religie en nagedachtenis, gaf 76% van diegenen die zich aanvankelijk ongemakkelijk voelden of nog geen beslissing hadden genomen, zich toch niet "ongemakkelijk" te voelen met de atlas. Als wij 10 anatomie afbeeldingen vergeleken, gaven de chirurgen aan, dat de Pernkopf atlas de beste anatomie details weergaf en dat het gebruik voor operaties beter was dan de Netter atlas. Samenvattend gaf deze studie inzicht in de meningen van chirurgen voor het gebruik van de Pernkopf atlas voor operaties en onderwijs.

In **hoofdstuk 6** werden de ethische en godsdienstige regels voor het gebruik van de Pernkopf atlas in chirurgie weergegeven. Er werd gebruik gemaakt van een 4 punten schaal voor ethiek om dilemma's in de praktijk te sturen.³¹ Dit betreft een dictaat – het Wenen Protocol – door Rabijn Joseph A. Polak, een Holocaust overlevende en Opperrechter van de New England rechtbanken voor rabijnen, die richtlijnen heeft gepostuleerd voor het gebruik van deze atlas gebaseerd op Joodse medisch ethiek.^{32,33} Een studie werd getoond, gebruikmakend van een 4 punten schaal, van een patiënten casus, waar het gebruik van de atlas nodig was om een operatie met succes uit te voeren. De 4 punten schaal om ethische dilemma's te behandelen bij problemen tijdens een operatie, bestond uit (1) herkennen van de noodzaak tot een pauze, (2) het raadplegen van een collega bij een acute ingreep, (3) noodzaak voor een ethisch anatomische raadpleging en indien nodig, (4) raadplegen van de Pernkopf atlas met respect, uit dankbaarheid en met de kennis de levens en het lijden van de slachtoffers. Deze studie geeft inzicht in de ethiek en, deels, de godsdienstige overwegingen komende uit de 4 punten schaal gebruikt voor het ethisch gebruik van de Pernkopf atlas in chirurgie en onderwijs.

CONCLUSIE

Leren via video is een effectieve wijze voor het verspreiden en implementeren van innovaties in snijdende vakken en voor het delen van "best practices" als ondersteuning voor evidence-based geneeskunden en cognitieve theorie voor multimedia leren (CTML). Onderwijs films kunnen zeer waardevol zijn voor het leren van operaties en klinisch berederen als zij nauwgezet en aantrekkelijk worden vervaardigd. Het ontwikkelen van een online platform voor onderwijs kan een leeromgeving lanceren voor chirurgische netwerken, waarin het verspreiden toepassen van kennis en research central staan. Ethische dilemma's, zoals de Pernkopf atlas, kunnen gebruikt om bewustwording te creëren voor de achtergrond van anatomie wetenschap en de toepassing van ethische richtlijnen. Het voorgestelde onderwijs network, met video leren, stelt experts en ervaren chirurgen in de gelegenheid om leermomenten in chirurgie uit te breiden. Hierdoor kunnen kansen gegeven worden over de hele wereld ongeacht de locatie, cultuur, geslacht en taal. Bovendien kan dit artsen in landen met een minder ontwikkelde gezondheidszorg helpen.

PUBLICATION LIST

PEER-REVIEW JOURNAL ARTICLES

Dengler J, Dolen U, Patterson JMM, Davidge KM, Kahn LC, **Yee A**, Mackinnon SE. Supercharge End-to-Side Anterior Interosseous-to-Ulnar Motor Nerve Transfer Restores Intrinsic Function in Cubital Tunnel Syndrome. 2020. [Under Review]

Padovano WM, Dengler J, Patterson JMM, **Yee A**, Snyder-Warwick AK, Wood MD, Moore AM, Mackinnon SE. Incidence of Nerve Injury After Extremity Trauma in the United States. 2020. [Under Review]

Yee A, Padovano WM, Patterson JMM, Pet MA, Zazulia AR, Dengler J, Novak CB, Coert JH, Mackinnon SE. Developing a Video-Based Learning Module to Teach Decision-Making for Cubital Tunnel Surgeries. 2020. [Under Review]

Yee A, Padovano WM, Fox IK, Hill E, Rowe AG, Brunt LM, Moore AM, Snyder-Warwick AK, Kahn LC, Wood MD, Coert JH, Mackinnon SE. Video-Based Learning in Surgery: Establishing Surgeon Engagement and Utilization of Variable-Duration Videos. *Ann Surg*. 2020. [In Press]

Dengler J, Padovano WM, Davidge KM, McKay VR, **Yee A**, Mackinnon SE. Dissemination and Implementation Science in Plastic Surgery: Perfecting, Protecting, and Promoting Innovation That Defines Our Specialty. *Plast Reconstr Surg*. 2020. [In Press]

Yee A, Padovano WM, Rowe AG, Hill EJR, Fox IK, Moore AM, Coert JH, Mackinnon SE. The Role of Surgical Video on Resident Performance of Carpal Tunnel Release: A Cadaveric Simulation-Based, Prospective, Randomized, Blinded Pilot Study. *Plast Reconstr Surg*. 2020;145(6):1455-1463.

Power HA, Kahn LC, Patterson JMM, **Yee A**, Moore AM, Mackinnon SE. Refining indications for the supercharge end-to-side anterior interosseous to ulnar motor nerve transfer in cubital tunnel syndrome. *Plastic Reconstr Surg*. 2020;145(1):106e-116e.

Domeshek LF, Novak CB, Patterson JMM, Hasak JM, **Yee A**, Kahn LC, Mackinnon SE. Nerve Transfers – A Paradigm Shift in the Reconstructive Ladder. *Plast Reconstr Surg Glob Open*. 2019;25;7(6):e2290.

Dengler J, **Yee A**, Mackinnon SE. Supraclavicular Approach to the Brachial Plexus: How I Teach It. *Ann Thorac Surg*. 2019;107(2):331-334.

Yee A, Hildebrandt S, Seidelman WE, Mackinnon SE. Letter to the Editor: Nazi Medicine – Part 2: The Downfall of a Profession and Pernkopf's Anatomy Atlas. *Clin Orthop Relat Res*. 2018;476(12):2465-2466.

Yee A, Zubovic E, Yu J, Ray S, Hildebrandt S, Seidelman WE, Polak JA, Grodin MA, Coert JH, Brown D, Kodner IJ, Mackinnon SE. RESPONSE TO REVIEWERS. *Surgery*. 2019;165(5):868-869.

Yee A, Zubovic E, Yu J, Ray S, Hildebrandt S, Seidelman WE, Polak JA, Grodin MA, Coert JH, Brown D, Kodner IJ, Mackinnon SE. Ethical considerations in the use of Pernkopf's Atlas of Anatomy: A surgical case study. *Surgery*. 2019;165(5):860-867.

Yee A, Coombs DM, Hildebrandt S, Seidelman WE, Coert JH, Mackinnon SE. In Reply: Nerve Surgeon's Assessment of the Role of Eduard Pernkopf's Atlas of Topographic and Applied Human Anatomy in Surgical Practice. *Neurosurgery*. 2018;83(4):E189.

Yee A, Coombs DM, Hildebrandt S, Seidelman WE, Coert JH, Mackinnon SE. Nerve Surgeon's Assessment of the Role of Eduard Pernkopf's Atlas of Topographic and Applied Human Anatomy in Surgical Practice. *Neurosurgery*. 2019;84(2):491-498.

Kahn LC, **Yee A**, Mackinnon SE. Important Details in Performing and Interpreting the Scratch Collapse Test. *Plast Reconstr Surg*. 2018;141(2):399-407.

Mundschenk MB, Odom EB, Ghosh TD, Kleiber GM, **Yee A**, Patel KB, Mackinnon SE, Tenenbaum MM, Buck DW 2nd. Are Residents Prepared for Surgical Cases? Implications in Patient Safety and Education. *J Surg Educ*. 2018;75(2):403-408.

Davidge KM, Gontre G, Tang D, Boyd KU, **Yee A**, Damiano MS, Mackinnon SE. The "hierarchical" Scratch Collapse Test for identifying multilevel ulnar nerve compression. *Hand (NY)*. 2015;10(3):388-395.

A

- Davidge KM, **Yee A**, Moore AM, Mackinnon SE. The Supercharge End-to-Side Anterior Interosseous-to-Ulnar Motor Nerve Transfer for Restoring Intrinsic Function: Clinical Experience. *Plast Reconstr Surg*. 2015;136(3):344e-352e.
- Barbour JR, **Yee A**, Moore AM, Trulock EP, Buchowski JM, Mackinnon SE. Cadaveric nerve allotransplantation in the treatment of persistent thoracic neuralgia. *Ann Thorac Surg*. 2015;99(4):1414-7.
- Tang DT, Barbour JR, Davidge KM, **Yee A**, Mackinnon SE. Nerve entrapment: update. *Plast Reconstr Surg*. 2015;135(1):199e-215e.
- Phillips BZ, Franco MJ, **Yee A**, Tung TH, Mackinnon SE, Fox IK. Direct radial to ulnar nerve transfer to restore intrinsic muscle function in combined proximal median and ulnar nerve injury: case report and surgical technique. *J Hand Surg Am*. 2014;39(7):1358-62.
- Davidge KM, **Yee A**, Kahn LC, Mackinnon SE. Median to radial nerve transfers for restoration of wrist, finger, and thumb extension. *J Hand Surg Am*. 2013;38(9):1812-27.
- Barbour J, **Yee A**, Kahn LC, Mackinnon SE. Supercharged end-to-side anterior interosseous to ulnar motor nerve transfer for intrinsic musculature reinnervation. *J Hand Surg Am*. 2012;37(10):2150-9.
- Ray WZ, Yarbrough CK, **Yee A**, Mackinnon SE. Clinical outcomes following brachialis to anterior interosseous nerve transfers. *J Neurosurg*. 2012;117(3):604-9.
- Mackinnon SE, **Yee A**, Ray WZ. Nerve transfers for the restoration of hand function after spinal cord injury. *J Neurosurg*. 2012;117(1):176-85.
- Kale SS, Glaus SW, **Yee A**, Nicoson MC, Hunter DA, Mackinnon SE, Johnson PJ. Reverse end-to-side nerve transfer: from animal model to clinical use. *J Hand Surg Am*. 2011;36(10):1631-39.e2.
- Ray WZ, Pet MA, Nicoson MC, **Yee A**, Kahn LC, Mackinnon SE. Two-level motor nerve transfer for the treatment of long thoracic nerve palsy. *J Neurosurg*. 2011;115(4):858-64.
- Pet MA, Ray WZ, **Yee A**, Mackinnon SE. Nerve transfer to the triceps after brachial plexus injury: report of four cases. *J Hand Surg Am*. 2011;36(3):398-405.
- Ray WZ, Pet MA, **Yee A**, Mackinnon SE. Double fascicular nerve transfer to the biceps and brachialis muscles after brachial plexus injury: clinical outcomes in a series of 29 cases. *J Neurosurg*. 114(6):1520-8.
- Brown JM, **Yee A**, Ivens RA, Dribben W, Mackinnon SE. Post-cervical decompression parsonage-turner syndrome represents a subset of C5 palsy: six cases and a review of the literature: case report. *Neurosurgery*. 2010;67(6):E1831-43; discussion E1843-4.
- Whitlock EL, Myckatyn TM, Tong AY, **Yee A**, Yan Y, Magill CK, Johnson PJ, Mackinnon SE. Dynamic quantification of host Schwann cell migration into peripheral nerve allografts. *Exp Neurol*. 2010;225(2):310-9.
- Magill CK, Moore AM, Yan Y, Tong AY, MacEwan MR, **Yee A**, Hayashi A, Hunter DA, Ray WZ, Johnson PJ, Parsanian A, Myckatyn TM, Mackinnon SE. The differential effects of pathway- versus target-derived glial cell line-derived neurotrophic factor on peripheral nerve regeneration. *J Neurosurg*. 2010;113(1):102-9.
- Ray WZ, Kasurkthi R, **Yee A**, Mackinnon SE. Functional recovery following an end to side neurorrhaphy of the accessory nerve to the suprascapular nerve: case report. *Hand (NY)*. 2010;5(3):313-7.
- Brown JM, **Yee A**, Mackinnon SE. Distal median to ulnar nerve transfers to restore ulnar motor and sensory function within the hand: technical nuances. *Neurosurgery*. 2009;65(5):966-77; discussion 977-8.
- Ray WZ, Kasurkthi R, Papp EM, Moore AM, **Yee A**, Hunter DA, Solowski NL, Mohanakumar T, Mackinnon SE, Tung TH. The role of T helper cell differentiation in promoting nerve allograft survival with costimulation blockade. *J Neurosurg*. 2010;112(2):386-93.
- Magill CK, Tuffaha SH, **Yee A**, Luciano JP, Hunter DA, Mackinnon SE, Borschel GH. The short- and long-term effects of Seprafilm on Peripheral nerves: a histological and functional study. *J Reconstr Microsurg*. 2009;25(6):345-54.

TEXTBOOK

Mackinnon SE, **Yee A**, ed. *Nerve Surgery*. New York, NY: Thieme Medical Publishers; 2015.

TEXTBOOK CHAPTERS

Boyd KU, Weber RV, **Yee A**, Mackinnon SE. Principles of Nerve Transfers. *Plastic Surgery (Volume 1, Principles 4th Edition)*. Gurtner GC, Neligan PC (eds). Elsevier, 2017.

Snyder-Warwick AK, **Yee A**, Mackinnon SE. *New Insights and Applications in the Treatment of Nerve Injuries*. Foker, Till, Holcomb III, Khan, Thomson (eds) Esophageal and Gastric Disorders in Infancy and Childhood. Springer, 2017.

Patterson JM, **Yee A**, Mackinnon SE. Motor Nerve Transfers for Radial and Ulnar Nerve Injuries. *Master Techniques in Orthopaedic Surgery (The Hand 3rd Edition)*. Morrey, Maschke, Graham, Evans (eds). Wolters Kluwer, 2016.

Mackinnon SE, **Yee A**. Brachial plexus decompression. *ESTS Textbook of Thoracic Surgery (Vol. 2)*. Kuzdzal, Jaroslaw (ed). Medycyna Praktyczna, 2015.

Fox IK, **Yee A**, Mackinnon SE. Sensory Nerve Transfers. *Operative Orthopedics of the Upper Extremity*. McGraw Hill, 2014.

Tang DT, **Yee A**, Mackinnon SE. Nerve Transfers in the Upper Extremity. *AAOS Orthopaedic Knowledge Online, Hand and Wrist*. American Academy of Orthopaedic Surgeons, 2012.

TEXTBOOK VIDEO CHAPTERS

Mackinnon SE, **Yee A**. Brachial Plexus Reconstruction. *Comprehensive Review of Neurosurgery*. Oakstone Medical Publishing, 2016.

Mackinnon SE, **Yee A**. Compression Neuropathy. *Comprehensive Review of Neurosurgery*. Oakstone Medical Publishing, 2016.

Mackinnon SE, **Yee A**. Nerve Transfers for the Forearm and Hand. *Comprehensive Review of Neurosurgery*. Oakstone Medical Publishing, 2016.

Mackinnon SE, **Yee A**. Nerve Transfers for Shoulder Function. *Comprehensive Review of Neurosurgery*. Oakstone Medical Publishing, 2016.

Mackinnon SE, **Yee A**. Strategies in Peripheral Nerve Surgery. *Comprehensive Review of Neurosurgery*. Oakstone Medical Publishing, 2016.

Mackinnon SE, **Yee A**. Nerve Injury and Repair. *Plastic Surgery by Peter Neligan*. Elsevier, 2016.

Mackinnon SE, **Yee A**. Surgeon as Perpetual Learner – Cases I Have Learned the Most From. *Peripheral Nerve Injuries and Brachial Plexus by David Netscher*. Taylor & Francis Group, 2016.

Mackinnon SE, **Yee A**. Thoracic Outlet Decompression. *ESTS Textbook of Thoracic Surgery*. Medycyna Praktyczna Cracow, 2014.

Mackinnon SE, **Yee A**. Compression Neuropathy. *Comprehensive Review of Neurosurgery*. Oakstone Medical Publishing, 2014.

Mackinnon SE, **Yee A**. Nerve Transfers for the Hand. *Comprehensive Review of Neurosurgery*. Oakstone Medical Publishing, 2014.

Mackinnon SE, **Yee A**. Nerve Transfers for Brachial Plexus Injuries. *Comprehensive Review of Neurosurgery*. Oakstone Medical Publishing, 2014.

Mackinnon SE, **Yee A**. Strategies in Peripheral Nerve Surgery. *Comprehensive Review of Neurosurgery*. Oakstone Medical Publishing, 2014.

Mackinnon SE, **Yee A**. Strategies for Nerve Reconstruction. *Comprehensive Review of Neurosurgery*.

Oakstone Medical Publishing, 2012.

Mackinnon SE, **Yee A.** Nerve Transfers for Brachial Plexus Injuries. *Comprehensive Review of Neurosurgery*. Oakstone Medical Publishing, 2012.

Mackinnon SE, **Yee A.** Compression Neuropathy. *Comprehensive Review of Neurosurgery*. Oakstone Medical Publishing, 2012.

EDUCATIONAL VIDEO ARTICLES

Pet MA, Brogan DM, Hacquebord JH, **Yee A.** Introduction to Microsurgery: Operating Room Setup, Microscope Setup, Ergonomics, Microsurgical Tools and Technique. WUSTL Learn Surgery, 2019.

Johnson JE, **Yee A.** Arthroplasty of the 1st Metatarsophalangeal (MTP) Joint Using Acellular Dermal Allograft for Advanced Hallux Rigidus. WUSTL Learn Surgery, 2019.

Boyer MI, **Yee A.** Proximal Row Carpectomy. WUSTL Learn Surgery, 2019.

Mackinnon SE, **Yee A.** Cross Palm Nerve Allografts for Early Sensory Restoration in a High Median Nerve Injury. WUSTL Learn Surgery, 2019.

Mackinnon SE, **Yee A.** Repair of a Digital Nerve Laceration with an Acellularized Nerve Allograft. WUSTL Learn Surgery, 2019.

Furlow LT, Snyder-Warwick AL, **Yee A.** Commentary: Furlow Double Opposing Z-Plasty Procedure for Secondary Palatoplasty. WUSTL Learn Surgery, 2019.

Snyder-Warwick AL, Furlow LT, **Yee A.** Furlow Double Opposing Z-Plasty Procedure for Secondary Palatoplasty. WUSTL Learn Surgery, 2019.

Mackinnon SE, **Yee A.** Electrodiagnostic Indications for Cubital Tunnel Surgery and Supercharge ETS Nerve Transfer. WUSTL Learn Surgery, 2019.

Goldfarb CA, **Yee A.** Volar Dome Osteotomy of the Distal Radius for Madelung's Deformity. WUSTL Learn Surgery, 2019.

Mackinnon SE, **Yee A.** Double fascicular nerve transfer. WUSTL Learn Surgery, 2018.

Aubuchon JD, **Yee A.** Airway Examination and Endotracheal Intubation. WUSTL Learn Anesthesiology, 2018.

Mackinnon SE, **Yee A.** Quadrangular space nerve release. PASSIO Education, 2018.

Cicero TJ, **Yee A.** Trends in Opioid Abuse: Prescription Abuse and Resurgence of Heroin. PASSIO Education, 2018.

Aubuchon JD, **Yee A.** Balancing Pain Control with the Opioid Epidemic. PASSIO Education, 2018.

Mackinnon SE, **Yee A.** Examination of a patient with deep motor branch ulnar neuropathy. PASSIO Education, 2018.

Brunt LM, **Yee A.** Laparoscopic cholecystectomy with intraoperative cholangiogram for systematic cholelithiasis. PASSIO Education, 2017.

Mackinnon SE, **Yee A.** Superficial radial sensory nerve release with tenotomy of the brachioradialis tendon. PASSIO Education, 2017.

Johnson SE, **Yee A.** Bridle procedure for treatment of foot drop. PASSIO Education, 2017.

Mackinnon SE, **Yee A.** Common peroneal nerve release at the fibular head. PASSIO Education, 2016.

Mackinnon SE, **Yee A.** Superficial peroneal nerve release in the lower leg. PASSIO Education, 2016.

Mackinnon SE, **Yee A.** Revision ulnar nerve transposition following failed submuscular ulnar nerve transposition. PASSIO Education, 2016.

Mackinnon SE, **Yee A.** Examination of a patient with multiple nerve injuries and neuropathic pain following a laceration at the distal forearm. PASSIO Education, 2016.

Mackinnon SE, **Yee A.** Carpal tunnel syndrome. PASSIO Education, 2016.

- Mackinnon SE, **Yee A**. Cubital tunnel syndrome. PASSIO Education, 2016.
- Mackinnon SE, **Yee A**. Thoracic outlet syndrome. PASSIO Education, 2016.
- Mackinnon SE, **Yee A**. Introduction to compression neuropathy. PASSIO Education, 2016.
- Mackinnon SE, **Yee A**. Strategies of peripheral nerve surgery. PASSIO Education, 2016.
- Mackinnon SE, **Yee A**. Sensory nerve transfers for hand function. PASSIO Education, 2016.
- Mackinnon SE, **Yee A**. Nerve transfers for median nerve injuries. PASSIO Education, 2016.
- Mackinnon SE, **Yee A**. Nerve transfers for radial nerve injuries. PASSIO Education, 2016.
- Mackinnon SE, **Yee A**. Introduction and indications for nerve transfers. PASSIO Education, 2016.
- Mackinnon SE, **Yee A**. Nerve transfers for shoulder and elbow function. PASSIO Education, 2016.
- Mackinnon SE, **Yee A**. Brachial plexus reconstruction. PASSIO Education, 2016.
- Mackinnon SE, **Yee A**. Surgeon as a Perpetual Learner – Nerve Cases I Have Learned Most From. PASSIO Education, 2016.
- Patterson GA, **Yee A**. Tracheal resection of a stomal stricture and repair following a tracheostomy. PASSIO Education, 2016.
- Mackinnon SE, **Yee A**. Saphenous nerve release. YouTube, 2015.
- Mackinnon SE, **Yee A**. Medial triceps to anterior branch of axillary nerve transfer in a case of specific reinnervation. YouTube, 2015.
- Mackinnon SE, **Yee A**. Medial triceps to axillary nerve transfer. YouTube, 2015.
- Mackinnon SE, **Yee A**. 2014 PRS – Supercharge nerve transfers. YouTube, 2014.
- Mackinnon SE, **Yee A**. Brachialis to anterior interosseous nerve transfer with extended forearm incision. YouTube, 2014.
- Mackinnon SE, **Yee A**. Median (FCR/FDS) to radial (PIN/ECRB) nerve transfers. YouTube, 2014.
- Mackinnon SE, **Yee A**. Posterior approach – spinal accessory to suprascapular nerve transfer. YouTube, 2014.
- Mackinnon SE, **Yee A**. Anterior interosseous to ulnar motor nerve transfer. YouTube, 2014.
- Mackinnon SE, **Yee A**. Superficial peroneal and sural neuroma transposition. YouTube, 2014.
- Mackinnon SE, **Yee A**. Radial nerve release at the spiral groove. YouTube, 2014.
- Zuker RM, Borschel GH, Snyder-Warwick AK, **Yee A**. Stage 1 – Cross-facial nerve grafting for smile. YouTube, 2014.
- Zuker RM, Borschel GH, Snyder-Warwick AK, **Yee A**. Segmental gracilis muscle transfer for smile in a case of Mobius syndrome. YouTube, 2014.
- Mackinnon SE, **Yee A**. 2014 FRS – Jumping the nerve gap. YouTube, 2014.
- Mackinnon SE, **Yee A**. 2014 CRN – Nerve transfers for the hand. YouTube, 2014.
- Mackinnon SE, **Yee A**. 2014 CRN – Brachial plexus lesions. YouTube, 2014.
- Mackinnon SE, **Yee A**. 2014 CRN – Peripheral nerve surgery. YouTube, 2014.
- Mackinnon SE, **Yee A**. 2014 CRN – Nerve transfers for the shoulder and elbow. YouTube, 2014.
- Mackinnon SE, **Yee A**. 2014 CRN – Compression Neuropathies. YouTube 2014.
- Mackinnon SE, **Yee A**. 2013 PRS – Nerve entrapment as CME update. YouTube, 2014.
- Mackinnon SE, **Yee A**. Revision carpal tunnel release in a case of persistent symptoms and incomplete release. YouTube, 2013.
- Mackinnon SE, **Yee A**. Posterior interosseous nerve release. YouTube, 2013.
- Mackinnon SE, **Yee A**. Third webspace to sensory component of ulnar nerve transfer and PCM to DCU nerve transfer. YouTube, 2013.

- Johnson JE, **Yee A.** Robert Jones dressing for the lower leg. YouTube, 2014.
- Mackinnon SE, **Yee A.** Long-term (4 Years) post-operative outcome following median to radial nerve transfers. YouTube, 2013.
- Lorna LC, **Yee A.** Motor re-education following median to radial nerve transfer. YouTube, 2013.
- Mackinnon SE, **Yee A.** Utility of scratch collapse test in a case of failed carpal tunnel release. YouTube, 2013.
- Mackinnon SE, **Yee A.** Hierarchical scratch collapse test. YouTube, 2013.
- Mackinnon SE, **Yee A.** Carpal tunnel release. YouTube, 2013.
- Mackinnon SE, **Yee A.** Localizing a secondary compression point with the hierarchical scratch collapse test. YouTube, 2013.
- Mackinnon SE, **Yee A.** Median nerve release in the forearm. YouTube, 2012.
- Lorna LC, **Yee A.** Motor re-education following reverse end-to-side anterior interosseous nerve transfer. Vimeo, 2012.
- Mackinnon SE, **Yee A.** Anterior interosseous to ulnar motor supercharge nerve transfer. Vimeo, 2012.
- Mackinnon SE, **Yee A.** Transmuscular ulnar nerve transposition in a case of traumatic medial cord injury. Vimeo, 2012.
- Mackinnon SE, **Yee A.** Revision carpal tunnel release in a case of proximal median nerve hematoma injury and mild compression. Vimeo, 2012.
- Mackinnon SE, **Yee A.** Ganglion cyst removal in the common peroneal nerve at the fibular head. Vimeo, 2012.
- Mackinnon SE, **Yee A.** 2012 CRN – Brachial plexus lesions. Vimeo, 2012.
- Mackinnon SE, **Yee A.** 2012 CRN – Supercharge nerve transfers and nerve transfers in the hand. Vimeo, 2012.
- Mackinnon SE, **Yee A.** 2012 CRN – Peripheral nerve surgery. Vimeo, 2012.
- Mackinnon SE, **Yee A.** 2012 VuMedi – Transmuscular ulnar nerve transposition. Vimeo, 2012.
- Mackinnon SE, **Yee A.** Pectoral fascicle of the middle trunk to spinal accessory nerve transfer. Vimeo, 2011.
- Mackinnon SE, **Yee A.** Median to radial tendon transfers: PT to ECRB, FCR to EDC, PL to EPL. Vimeo, 2011.
- Fox IK, **Yee A.** End-to-end epineurial nerve repair in a rat model. Vimeo, 2011.
- Mackinnon SE, **Yee A.** Superficial peroneal nerve release in the lower leg. Vimeo, 2011.
- Mackinnon SE, **Yee A.** Tarsal tunnel release. Vimeo, 2011.
- Fox IK, **Yee A.** Ulnar index of median to ulnar ring of ulnar sensory nerve transfer and prevention of proximal neuroma. Vimeo, 2011.
- Mackinnon SE, **Yee A.** Common peroneal nerve release at the fibular head. Vimeo, 2011.
- Mackinnon SE, **Yee A.** Flexor digitorum profundus tenodesis (median FDP to ulnar FDP). Vimeo, 2011.
- Mackinnon SE, **Yee A.** Median (FCR/FDS) to radial (PIN/ECRB) nerve transfer with pronator teres to ECRB tendon transfer. Vimeo, 2011.
- Mackinnon SE, **Yee A.** Thoracic outlet decompression. Vimeo, 2011.
- Mackinnon SE, **Yee A.** Medial triceps branch to axillary nerve transfer. Vimeo, 2011.
- Mackinnon SE, **Yee A.** Flexor digitorum superficialis to anterior interosseous nerve transfer. Vimeo, 2011.
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- Mackinnon SE, **Yee A**. Tibial nerve decompression at the soleus. Vimeo, 2011.
- Mackinnon SE, **Yee A**. Thoracodorsal to long thoracic nerve transfer. Vimeo, 2011.
- Mackinnon SE, **Yee A**. Median nerve forearm decompression. Vimeo, 2011.
- Mackinnon SE, **Yee A**. Guyon's canal and carpal tunnel release. Vimeo, 2011.
- Mackinnon SE, **Yee A**. Submuscular ulnar nerve transposition. Vimeo, 2011.
- Mackinnon SE, **Yee A**. Carpal tunnel release. Vimeo, 2011.
- Mackinnon SE, **Yee A**. Double fascicle transfer: median fascicle to biceps branch and ulnar fascicle to brachialis branch nerve transfers. Vimeo. 2011.
- Mackinnon SE, **Yee A**. Examination example of non-nerve related pain. Vimeo, 2011.
- Mackinnon SE, **Yee A**. Anterior interosseous to ulnar motor (reverse end-to-side) nerve transfer. Vimeo, 2011.

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BIOGRAPHY

Andrew Yee was born on March 26, 1985 in Boston, Massachusetts and grew up in central Massachusetts and Brookline. He earned his Bachelor's degree in biotechnology at Rochester Institute of Technology in 2007. His first job after college came from a referral from the anatomy lab in college to be a research assistant in the Peripheral Nerve Research Laboratory at Washington University School of Medicine to perform histomorphometry and electron microscopy. Over the next several years, his role shifted towards clinical research and education due to his interests in medicine, media, design, and technology. In 2011, he developed an educational website and launched a *YouTube* channel called *Nerve Surgery* by producing a series of surgical videos on his spare time. He received experience in nerve surgery and was contributing editor for the textbook *Nerve Surgery*, which was published in 2015. He received entrepreneurship training from the Skandalaris Center at Washington University in St. Louis in 2014, and co-founded and launched *PASSIO Education*, as a video-based learning platform for learning operative techniques and clinical judgment from the masters of surgery. In 2016, he began his PhD in the Washington University – Utrecht University collaborative doctoral program in health professions education based on his work on video-based learning. When *PASSIO Education* was acquired by Washington University in 2018, he became the director of the Washington University *Learn Surgery* program. He continues to be a surgeon educator with a passion in medicine, implementation, digital technologies, design, and creativity, and has the distinct pleasure of working with learners and expertise of all levels from around the world.

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