# Videolaryngoscopy:

a small step for men,
a giant leap for mankind,
a monumental leap forward in intubation technology

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Videolaryngoscopie:
een kleine stap voor een mens, een enorme sprong voor de mensheid,
een monumentale sprong voorwaards in intubatietechnologie.

(met een samenvatting in het Nederlands)

Proefschrift

ter verkrijging van de graad van doctor aan de Universiteit Utrecht op gezag van de rector magnificus, prof. dr. G.J. van der Zwaan, ingevolge het besluit van het college voor promoties in het openbaar te verdedigen op dinsdag 12 september 2017 des middags te 12.45 uur

door

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geboren op 6 september 1983
te Heerlen

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## CONTENT

# Chapter 1

## Introduction

Patients require general anaesthesia for a broad range of surgical procedures. After they receive general anaesthesia, they lose their protective airway reflexes and therefore require a secured airway. This is the core business of the anaesthetist.

The airway can be secured by placing a tracheal tube (TT) through the vocal cords, into the trachea of the patient. A TT allows unobstructed spontaneous ventilation or artificial ventilation to ensure adequate oxygenation of the lungs. At the same time, a well-sealed cuffed TT protects the lungs from aspiration of gastric content.

## First attempts to get access to the trachea

The human trachea, however, was not 'designed' to be intubated. Since time immemorial, mankind has been searching for a way to secure the airway. Alexander the Great (356-323 BC), for example, reportedly engaged in airway management when a soldier suffocated on an aspirated bone and he performed a tracheostomy.[1] Over the centuries, pioneers of laryngoscopy have been searching for an instrument to get a direct view of the glottis and intubate the trachea. One major obstacle was illumination. The lack of a direct light source and thus the need for mirrors made instruments bulky and difficult to handle.[1]

The first direct laryngoscopy (DL) is often attributed to Alfred Kirstein in 1895.[2] Chevalier Jackson was the first to describe the combination of direct visualisation of the larynx with tracheal intubation. In 1903, he designed his first laryngoscope, a U-shaped tubular instrument with a spatula and a tubal handle.[3] In 1913, he was the first to report a high rate of success for using DL to intubate the trachea.[4] In the same year Chevalier Jackson published his article, Henry Janeway published a paper on his design of a battery-powered laryngoscope, solely dedicated for tracheal intubation.[5] Following World War I, endotracheal anaesthesia became increasingly prevalent.[6] In the 1930s a plethora of laryngoscope blades were designed; Robert Miller (1906-1976) described his so-called "Miller-blade" in 1941.[7] Professor Sir R. R. Macintosh (1897–1989), was the first to suggest routinely placing the blade's tip in the vallecula and then indirectly lifting the epiglottis.[8] This curved laryngoscopy blade introduced by Macintosh in 1943 remains to be the most widely used blade design for tracheal intubation.[9]

## Modern practice of laryngoscopy and tracheal intubation

Nowadays, general anaesthesia is administered daily in hospitals around the world for a variety of surgical interventions and is a cornerstone of modern medical practice (worldwide, more than 300 million surgical interventions are performed every year under general anaesthesia alone).[10, 11]

The classic, direct laryngoscope used for tracheal intubation is essentially a curved (mostly Macintosh) blade with a handle such that the anaesthetist can use this to manipulate the tongue and other soft-tissues of the mouth and palate to facilitate a direct view of the larynx and glottic arch. The TT is then introduced through the mouth or nose and correctly positioned by the anaesthetist using a direct view.

## Tracheal intubation – a complex interactive act between anaesthetist and patient's airway

Tracheal intubation is a task involving a complex, dynamic interaction between the operator, the airway device and the patient.[12] Many factors influence the ease of intubation including limited mobility of the mouth opening or neck, irregular anatomy of the mouth and larynx, tumour, or most commonly amongst modern patient populations, obesity.[13]

Research showed the incidence of failed intubation to be 1 in 1-2,000 (elective operations under elective controlled conditions by experienced anaesthetists). The incidence of failed intubation increases to 1 in 50-100 when intubation has to be achieved in an emergency setting (Emergency Department, Intensive Care Unit and pre-hospital setting), highlighting the importance of different factors when tracheal intubation has to be performed.[14]

Tracheal intubation can be difficult or may even fail. Difficult and failed tracheal intubations are important, as they can have major consequences: they are associated with oxygen desaturation (<90%), hypertension (>200 mmHg), dental damage, admission to the Intensive Care Unit and complications at extubation.[15] They are also associated with arrhythmias, bronchospasm, airway trauma, awareness and the sequelae of hypoxia (cardiac arrest, brain damage and even death). Difficulty or even failure of tracheal intubation can thus have major consequences. When tracheal intubation proves to be difficult, there is a tendency for the anaesthetist to repeat the attempt at tracheal intubation several times, perhaps followed by another anaesthetist doing the same. The fourth National Audit Project (NAP4) has shown this to increase the risk of progression to a 'can't intubate can't ventilate' (CICV – or can't intubate can't oxygenate (CICO)) situation[16] and the American Society of Anesthesiologists' Closed Claims Project (ASACCP) analysis suggested an increase in death and brain damage in such cases.[17] Mort reported a dramatic increase in airway complications when >2 direct laryngoscopies were performed.[18] When DL is unsuccessful, further attempts with the same technique have a close to 80% failure rate while alternative techniques (e.g. supraglottic airway devices and videolaryngoscopy) are more successful.[18]

## Can't intubate can't oxygenate (CICO) situations

Due to the severity of the threat from hypoxia, a tracheotomy (or cricothyrotomy) may be performed to secure the patient's airway. Evidence exists that there is a threshold for anaesthetists to perform a tracheotomy or cricothyrotomy. In the ASACCP analysis of difficult airway management a surgical airway was performed but too late in two-thirds of the cases. It was often performed when the patient was either moribund or in fact dead.[17] Similarly, in NAP4 there was evidence of delay and even cases where it was not performed at all despite clear need. There is a natural reluctance to perform such techniques.[16] Therefore, even where absolute impact of developments in airway management techniques may be modest, the sheer number of patients receiving anaesthesia will mean there is a huge potential increase in patient safety.[20] The former highlights the importance and added value of a tracheal intubation technique that decreases the chances of reaching a situation asking for a tracheotomy.

### Laryngoscopes and adjuncts in airway management

The clear and present danger to the patient of failure to quickly and easily intubate and also the threshold for anaesthetists to perform a tracheotomy when tracheal intubation fails, has led to the development of many different devices, tools and adjuncts to aid intubation. For almost 90 years since Magill designed his laryngoscope and more than 70 years from the introduction of Miller's straight and Macintosh's curved laryngoscopy blades, laryngoscopy essentially remained unchanged.[2] By the mid-80s the flexible fibreoptic scope was a common addition to difficult airway management trolleys for anaesthesia departments. The fibreoptic scope provides the anaesthetist with an indirect view of the larynx usually superior to the direct view. However, this indirect view complicates the dexterous task of inserting the TT. Moreover, surveys revealed that the prevalence of fibreoptic intubation skills is lacking among anaesthetists and practice is of utmost importance to remain skills.[21]

### Videolaryngoscopy changed the world forum of airway management

In the 1990s rigid fibreoptic endoscopy was introduced (Bullard scope[22], Wu scope[23], UpsherScope[24]). From 2000 onwards, there has been a plethora in the development of different indirect videolaryngoscopes (VLS). The VLS currently available can be roughly divided into two groups: channelled and non-channelled. The non-channelled VLS can be divided into acutely angulated (also called extra-curved) and non-angulated. The non-angulated devices approximately retain the traditional shape of classic laryngoscopes, but include optics at the distal end of the blade to provide a closer view of the relevant anatomy. This means that the anaesthetist can choose to perform the intubation using the direct line of sight (similar to classic DL) augmented by the indirect view from the optics in the blade tip. The other option is to only use the indirect view projected on a screen provided by the optics in the blade tip. The acutely angulated VLS require another technique of intubation; they have to be placed over the centre of the tongue, instead of moving the tongue to the left of the mouth. Because they have an acute curvature, a direct view of the larynx is not possible and a curved stylet is often used to guide the TT in the right direction. With these devices, during tracheal intubation, only the indirect view can be used.

Despite the many new devices that are put on the market for airway management every year, there are no requirements for manufacturers to prove clinical efficacy before marketing.[25-27] On top of that, new devices have to compete with a device, namely the classic direct laryngoscope, that has proven its efficacy over nearly 100 years. The widespread experience of anaesthetists worldwide with classic DL should not be underestimated, but neither should the morbidity and mortality of difficult and failed tracheal intubation. The evidence speaks in favour of videolaryngoscopy in different categories of patients.[28] It can be valuable in obese patients,[29] emergency airway management,[30] in reducing the risk of dental trauma,[31] as rescue device for unexpected, difficult airways,[32] and most significantly, may decrease the number of difficult intubations.[33] But it is of utmost importance to identify the VLS that perform best. It is highly unlikely that all offer equal benefit and some may even offer none.[33]

### Objectives of this thesis

The question rises what the position of VLS is in the current world of airway management. Since their introduction, VLS have become available in a range of different shapes and designs. Should these relatively new devices be used in all patients undergoing airway instrumentation or should they be reserved for a certain category of patients? If so, do they even have an added value for users experienced with classic DL? Do VLS offer enough added value to replace DL as the standard of care? In other words, should they be used for all intubations, elective and emergency? If they ever ultimately replace DL all together, is there educational added value of these devices and is there a videolaryngoscope that performs best in terms of educating the new generation? And, very important, what are the consequences for the patient? Will the use of VLS result in less complications associated with tracheal intubation?

### Research questions in this thesis

Originating from these considerations, we formulated the following research questions, which we aim to answer in this thesis.

- What is the historical background of direct laryngoscopy against which videolaryngoscopy was developed? (Chapter 2)
- Is videolaryngoscopy superior to classic direct laryngoscopy for patients with a known difficult airway when used by personnel experienced with direct laryngoscopy? (Chapter 3)
- Is one videolaryngoscope superior compared to others for users with different levels of experience when confronted with patients with a normal airway? (Chapter 4)

- Do differences between videolaryngoscopes potentially result in differences concerning the risk for complications, e.g. oropharyngeal, mucosal or dental trauma? (Chapters 5 and 6)
- Does combining the videolaryngoscope with a rigid intubation endoscope provide the anaesthetist with a trustworthy and valuable alternative intubation technique when confronted with patients with a very difficult airway? (Chapters 7 and 8)

**Outline of the thesis**

Previous studies from our research group laid the foundation for this thesis and highlighted the many advantages of videolaryngoscopy over classic DL.[35] Over the years, the number of different VLS keeps growing. It is an intriguing journey from the quest for a technique to make DL - and thus tracheal intubation - possible to the development of videolaryngoscopy (Chapter 2).

In Chapter 3, the literature was systematically searched to see if the apparently obvious advantages of videolaryngoscopy hold when videolaryngoscopy is compared to DL for experienced anaesthetists, confronted with patients with difficult airways.

The available VLS differ substantially, as does the background of the healthcare providers using them. Chapter 4 evaluates different VLS when used by healthcare professionals with different levels of experience in airway management. The added value of VLS in patients with difficult airways is well known, Chapter 4 evaluates if this is also true for patients with normal airways.

VLS do have certain limitations, which can result in complications. Several manufacturers advocate the use of a styletted TT, which can traumatize the patient. The risk for these complications partly occurs because the operator is looking at the screen instead of in the oral cavity during the actual insertion of the TT while the tube passes the palatopharyngeal wall. The risk increases when the oral cavity is poorly lit and narrow (e.g. high arched palatum), especially when a bulky VLS is used. To be able to make a risk assessment concerning trauma to the oral cavity when using different VLS, illumination of the oral cavity by different VLS was evaluated scoring the luminescence production by each videolaryngoscope in Chapter 5.

Overall, the use of VLS results in less complications, as was highlighted by earlier work of our research group. One of the complications that is less frequent when using videolaryngoscopy is dental trauma. To quantify the difference in risk for dental trauma between different VLS and DL, the forces applied to upper and lower teeth were evaluated in Chapter 6.

Chapter 7 reports about the tracheal intubation of a patient with a known very difficult airway. This patient was successfully and easily intubated using a technique combining a videolaryngoscope with a Bonfils® intubation endoscope. In Chapter 8, this combined intubation technique is evaluated in a cohort of patients with suspected or known difficult airways. Two independent anaesthetists evaluated the added value of this technique.

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# Chapter 2

## Pioneers of laryngoscopy: indirect, direct and video laryngoscopy

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## ABSTRACT

Airway management is one of the core skills of the anaesthetist. Various techniques of airway management have developed over many years.

Initially, the only view of the glottis that could be obtained was an indirect view (indirect laryngoscopy). Late in the 19th century a direct view of the glottis was obtained via various direct laryngoscopes. Currently, in the early 21st century, there has been a return to indirect laryngoscopy via videolaryngoscopy using a videolaryngoscope.

The aim of this paper is to give a historical overview of the development of both direct and indirect laryngoscopy.

## INTRODUCTION

Airway management is one of the core skills of the anaesthetist, either via facemask ventilation, insertion of a laryngeal mask airway, tracheal intubation by direct or indirect (video-assisted) laryngoscopy or by use of a fibrescope. Laryngoscopic tracheal intubation often requires the use of adjuncts such as a gum elastic bougie or stylet. Anaesthetists may also be required to perform a cricothyroidotomy or an emergency tracheostomy.

Elective intubation was only possible from the late 19$^{th}$ century. Prior to this the only method of securing an airway in a patient in respiratory distress was via a tracheostomy. Alexander the Great (356-323 BC) reportedly performed an emergency tracheostomy on a soldier suffocating from an aspirated bone, and reference to a surgical tracheostomy can be traced back as far as the Bronze Age.[1, 2]

"Laryngoscope" is a generic term for a device that is used to visualize the larynx.[3] The laryngoscope was initially a tool developed solely for the otorhinolaryngologist. In the early 20$^{th}$ century, advances in anaesthesia made the laryngoscope and the skills to successfully use it essential for the anaesthetist.[4]

Anaesthesia textbooks prior to the 1940s described three main methods of intubation: blind tactile intubation, blind nasal intubation, and intubation using direct laryngoscopy (DL). However, the majority of anaesthetists struggled to expose the glottis of unparalysed patients prior to the discovery and use of curare by Griffith in 1942. Any attempt at intubation before 1942 required 'deep' planes of anaesthesia.[5]

In this review, we aim to highlight the development of laryngoscopes and laryngoscopy.

## VISUALIZING THE LARYNX; EARLIEST HISTORY

It is probably impossible to identify the originator of any specific airway management technique or airway tool. However, many of these have recurred periodically for almost 4,000 years. Hippocrates (460-380 BC) was one of the first to describe tracheal intubation to support ventilation. Later, the Muslim philosopher and physician Avicenna (980-1037 AD) described tracheal intubation using "a cannula of gold or silver".[4] Dental mirrors of highly polished metal were used to examine the oral cavity during the time of the Roman Empire.[6]

In the seventh century, the Byzantine physician, Paul of Egina, described an instrument called the 'glossotrochus'. It was a polished steel blade used as a tongue depressor, held in place by a horseshoe-shaped attachment fastened under the patient's chin. Its purpose was to provide illumination of the fauces.[7]

In 1543 Andreas Vesalius, at that time professor at the University of Padua, described an instrument for intubation in his work "De Humani Corporis Fabrica Libri Septem". [8]

In 1743 André Levret, a French obstetrician, devised a gynaecological speculum. He also described to use the speculum with a snare to remove choanal polyps[9], however, it had limited use because of the lack of a light source.[6] The lack of illumination for examination of body cavities hindered the development of laryngoscopy. Following Levret's speculum another obstetrician, Benjamin Pugh, used an air-pipe for neonatal resuscitation.[10]

In 1807 a German, Dr. Philipp von Bozzini, described the "Lichtleiter" or light conductor[11], which consisted of two parallel tubes with mirrors. The light source was a candle, housed in the hollow handle and attached to a speculum. One tube (or channel) was used for illumination while the other channel was used for visualization. This device allowed Bozzini to view the nasopharynx, hypopharynx and larynx in cadavers. However, no mention was made if the interior of the larynx could be viewed, neither does a record of its use in clinical practice exist. The instrument itself was large (33 cm long and correspondingly wide) and, hence, was not easy to handle. His work was condemned, particularly in Vienna, which ironically later became the leading centre for laryngology. However, Bozzini was the first to introduce the idea of an external light source for illumination during examination of a body cavity.[1, 6, 12]

In 1829, Dr. Senn of Geneva made a small mirror, which could be placed at the back of the pharynx to view the glottis[13], but he abandoned it later because he said it was impractical to use.[7, 14]

## FROM GLOTTISCOPE TO LARYNGOSCOPE

It is debatable who was the first to develop the precursor to the modern laryngoscope, Benjamin Guy Babington or Manuel Garcia II. Rather than enter the debate a brief overview of the work of both pioneers is presented here.

### Benjamin Guy Babington (1794-1866)

Benjamin Guy Babington (Figure 1) presented his laryngoscope (he called it a 'glottoscope' which sometimes is referred to as the 'glottiscope') to the Hunterian Society in 1829 and at the same time published a report describing it in The London Medical Gazette, volume 3, page 555.[6] The 'glottoscope' consisted of a speculum to displace the tongue (a tongue depressor) and a system of mirrors to visualize the larynx with sunlight for illumination. It was the first device to use retraction of pharyngeal and supraglottic tissues to obtain a better view of the laryngeal inlet.[3] The patient was seated with his back to the sun and the physician held a flat or plane hand mirror in the left hand reflecting the sun's light to the back of the patient's pharynx. The spatula with an attached mirror was introduced with the right hand. Unfortunately, the original instrument has now vanished. Although Babington was able to view the larynx there was no reference concerning observation of the vocal cords. He failed to publish any clinical papers that described practical use of the instrument in laryngoscopy.

**Figure 2.1:** Benjamin G. Babington (Courtesy: Welcome Library, London)

There were only two papers published concerning Babington using his 'laryngoscope'. One by a Dr Gibb[15] who described a personal account of Babington performing laryngoscopy on him, another in 1864 by Mackenzie[16] entitled "A description of the first laryngoscope as invented and employed by Dr Benjamin Babington in the year 1829".[4, 6, 17] The term "laryngoscope" appears to have been used for the first time by dr. Thomas Hodgkin (famous for Hodgkin's disease and a colleague of Babington).[14]

### Manuel Patricio Rodríguez Garcia (1805-1906) or Manuel Garcia II

Manuel Garcia II was considered to be the first individual to view the functioning glottis in its entirety. [4] In 1881, in a paper called "Physiological Observations on the Human Voice", presented at the Seventh International Congress of Medicine held in London,[17, 18] Garcia described the action of the vocal cords during inspiration and vocalization and production of sound in the larynx.[6] Garcia claimed that he was not only the first to describe a technique of laryngoscopy, but also the first to evaluate the physiology of the larynx. This claim led to the controversy over who was the first to devise a means of viewing the larynx.[1] Because Garcia was non-medical it was presumed that he was unaware of Babington's 'glottoscope'. In fact, the majority of the medical profession at that time was also unaware of it. It is not known whether Babington was cognizant of García's claim even though he was a member of the Royal Society's Council.
In the intervening years of Babington's and Garcia's inventions there were sporadic references to developments in clinical laryngoscopy. Dr. M. Baumes of Lyons mentioned laryngoscopy as being useful in his practice (1838).[19] A Scottish surgeon, Robert Liston, described a similar instrument, "a glass such as is used by dentists, with a long stalk".[19] Dr. Warden of Edinburgh, Scotland, employed a glass prism and reported two cases in which he had "satisfactory ocular inspection of diseases affecting the glottis" (1845).[19] Mr. Avery, a Londoner, was the first to design a head mirror that concentrated candle light to allow the viewing of the larynx through a device that was quite similar to that described by Bozzini.[6, 19]

## THE "TURCKISH WAR" ON LARYNGOSCOPY IN CLINICAL PRACTICE: TURCK VS. CZERMAK

In 1857, Dr. Ludwig Turck of Vienna unsuccessfully tried to apply Garcia's method of laryngoscopy into his clinical practice at the Vienna Hospital. He first tried laryngoscopy on cadavers then on himself and finally on his patients. However, his attempts failed because sunlight proved to be an inadequate light source. He temporarily abandoned any further effort.[6, 12, 20]

In November 1857, Professor Johann Nepomuk Czermak of Budapest (Figure 2) perfected a system for laryngoscopy, which incorporated a system of mirrors that had been used by Turck, into clinical practice. He substituted a brighter artificial light source for sunlight and was able to focus the light by using a concave ophthalmic examining mirror. At first the mirror was held between his teeth to focus the reflected light to the posterior pharynx. Later a hole was made in the mirror enabling direct vision on the pharynx.[8] He published his findings in March 1858 in the Wiener Medizinische Wochenschrift[21] and deserves the credit for being the first to successfully use laryngoscopy clinically.[6] He made this claim to the Society of Physicians on April 9, 1858. Czermak was also probably the first to employ external laryngeal counter pressure to the thyroid cartilage while performing indirect laryngoscopy to improve laryngeal exposure.[22] It is known today as the "BURP" manoeuvre (Backward Upward Right Pressure) to improve laryngeal view with a conventional blade during tracheal intubation.[3]

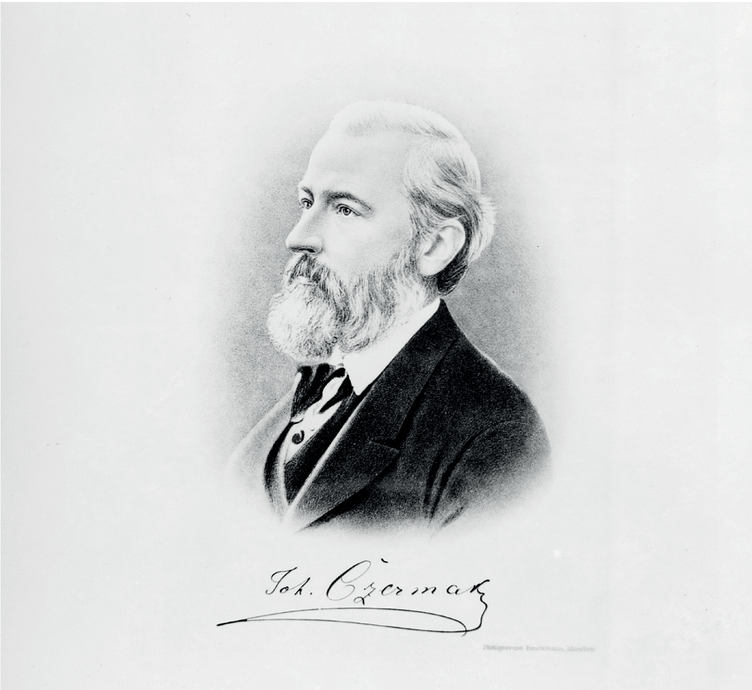


**Figure 2.2:** Johann N. Czermak (Courtesy: Welcome Library, London)

Despite the success of Czermak's work, Turck claimed to be the first to use laryngoscopy clinically, however, this claim lacked documentation. On April 14, 1858, Czermak acknowledged Turck's claim, but withdrew this acknowledgment in subsequent publications. This started the dispute between Turck and Czermak nicknamed "the Turckish war".[1] The French Academy of Sciences was unable to decide who was correct and so divided a medal between them.[7] Publications and counter-publications followed.[22, 23, 24] In early 1859 both Turck and Czermak published several pathologic cases observed by the laryngoscope. Czermak published and travelled widely, lecturing about his new technique, while Turck documented clinical findings on laryngeal pathology.[1]

## FROM INDIRECT TO DIRECT LARYNGOSCOPY

In 1852 Horace Green reported the first DL in a child with intermittent airway obstruction. His paper was titled "On the Surgical Treatment of Polypi of the Larynx, and Edema of the Glottis".[25] Green used a bent tongue spatula, and sunlight for illumination while the patient was facing him. This paper was relegated to obscurity despite the fact that the field of laryngology developed later that decade.[3, 26]

### Alfred Kirstein

The first DL is often attributed to Alfred Kirstein in 1895. Kirstein may have been motivated by the interest in direct visualization of the vocal cords because of Kaiser Frederick's death from laryngeal cancer in 1888.[4,27] It took many years following the introduction of indirect laryngoscopy for Kirstein to develop a direct laryngoscope due to lack of an appropriate light source. Once an adequate light source was designed various endoscopes were developed; firstly bronchoscopes, followed by gastroscopes, cystoscopes, and laryngoscopes.[1]

It is thought that Kirstein developed DL following an accidental tracheal intubation by one of his colleagues while trying to perform an endoscopic oesophagoscopy. Kirstein then developed his "autoscope". [4] Because the laryngoscope was synonymous with the laryngeal mirror, he carefully named his method "autoscopy" to avoid controversy.[3, 27] His autoscope had an external electrical light source.[2] He carefully reported his technique and instrumentation, detailing the ideal head and neck position (sniffing) as well as the vector forces required for successful laryngeal exposure. As a result, Kirstein has become known as the pioneer of DL.[3]

### Chevalier Jackson

Chevalier Jackson (Figure 3), Professor of Laryngology at Jefferson Medical College in Philadelphia, Pennsylvania, was the first to describe the combination of direct visualization of the larynx with tracheal intubation. In 1903, he designed his first laryngoscope, a 'U' shaped tubular instrument with a spatula and a tubal handle.[28] His original laryngoscope required the use of a headlight, but later he designed a laryngoscope blade with a distal light source rather than the proximal design used by Kirstein. Distal illumination was crucial for effective use of his laryngoscope because of the lateral approach through the oral cavity and oropharynx. Previous spatula laryngoscopes were placed in the midline and vallecula using headlight illumination.[4, 26]

**Figure 2.3:** Chevalier Jackson (Courtesy: Welcome Library, London)

Jackson initially performed DL as Kirstein had described it with the patient in the sitting position, the neck flexed at the chest, and the head extended at the occipital joint. Jackson later (at the beginning of the 20$^{th}$ century) introduced supine DL with the head raised by an assistant (Jackson's assistant was named Boyce). Kirstein's position was therefore achieved in the supine patient. Jackson believed that raising the head was an extremely important manoeuvre for successful DL and that the assistant's role of maintaining the head and neck position was crucial. He honoured his assistant in naming this position the Boyce-Jackson position.[3, 26, 29]

The development of today's laryngoscopes and lateral approach were dependent on Jackson's introduction of distal illumination. Jackson published his work in 1913 in an article entitled "The technique of insertion of tracheal insufflation tubes."[4, 26, 30]

Over the next two decades, Jackson designed a number of laryngoscopes. He experimented with a variety of shapes. Another important feature of Jackson's laryngoscopes was the ergonomic handle. Significant force was often required for DL because it was done by means of local anaesthesia. A comfortable handle was critical to maintain the exposure, especially for long procedures and for patients with difficult airway anatomy.[26] The techniques used today still owe much to Jackson.[1]

## Henry Harrington Janeway

Henry Harrington Janeway (Figure 4), an American anaesthetist practicing at Bellevue Hospital in New York in 1913 was the first anaesthetist to publish on DL. In the same year Chevalier Jackson had published his article, Janeway published an article entitled "Intratracheal anaesthesia from the standpoint of the nose, throat and oral surgeon with a description of a new instrument for catheterizing the trachea."[31] All publications on DL prior to his work were by surgeons.


**Figure 2.4:** Henry H. Janeway (Courtesy: Radium 1921; 16:82)

He designed a battery-powered laryngoscope, solely dedicated for tracheal intubation. The "speculum" Janeway designed incorporated a distal light source with battery power within the laryngoscope handle itself. This handle-inclusive battery power was the first of its kind. Additional features included a shortened distal end of the speculum that eliminated the need for a telescope to adequately view the larynx. It also incorporated a central notch for maintaining the catheter in the midline during placement, and a curve to the distal end of the blade to help direct the catheter through the vocal cords. However, Janeway's laryngoscope never gained widespread popularity.[2, 4, 31]

## MAGILL, ROWBOTHAM, MILLER AND MACINTOSH

Following the First World War tracheal anaesthesia became increasingly popular.[4] Two British anaesthetists Sir Ivan Whiteside Magill (1888-1986) and Edgar Stanley Rowbotham (1890-1979), realized that reconstructive facial surgery performed on disfigured soldiers was easier and more successful under general anaesthesia with the airway secured by a tracheal tube (TT).[2] From 1920 they described various methods to provide safe general tracheal anaesthesia during facial surgery.[4, 32, 33, 34] In 1926, Sir Magill designed his original 'U' shaped laryngoscope which was a modified version of a laryngoscope designed by Hill in 1910 ('Hill's laryngoscope') which itself was also a modified version of Jackson's laryngoscope. Magill put batteries in the handle and later modified this laryngoscope to be a 'folding' type.[32, 35, 36] The famous "Magill forceps" were based on Rowbotham's 'rod' – a rod used to place an intratracheal catheter during insufflation anaesthesia. However, the question still remains on why Rowbotham has not received the accolades awarded to Magill when Magill adapted many of Rowbotham's ideas and observations (opinion of one of the authors – CA).[37, 38]

John S. Lundy, head of the section on anaesthesia at the Mayo Clinic, Rochester, Minnesota, met Sir Ivan Magill at a medical meeting in 1930. During this meeting Magill taught Lundy his method of tracheal intubation.[39] Lundy and his Mayo Clinic colleagues not only embraced this technique by publishing several articles on laryngoscopy[40, 41] and intubation but also designed a rigid bladed laryngoscope called the 'Lundy scope' which incorporated its own light source powered by a dry-cell battery.[4]

There was a plethora of laryngoscope blade designs being developed at this time. Robert Arden Miller, practicing at San Antonio, Texas described his 'straight' laryngoscope blade (the so-called 'Miller blade') in Anesthesiology in 1941.[42] Although the Miller blade is regarded as a straight blade it has a small curve 5 cm from its tip.[4] The blade was designed to directly lift the epiglottis. Anaesthetists and ENT surgeons are today still using this blade.[43, 44]

Robert Reynolds Macintosh, later Professor Sir R R Macintosh (1897-1989), believed that the hallmark of a successful anaesthetist was 'the ability to pass a tracheal tube under direct vision'.[45] Prior to 1943 poor straight-blade techniques hindered the development of laryngoscopy. The majority of anaesthetists struggled to expose the vocal cords of an unparalysed patient prompting Macintosh to comment that intubation required a 'tour de force'.[46] The most popular method of DL involved the midline approach passing a straight-blade laryngoscope beyond the epiglottis 'in order to evert it' even though Magill had clearly described the technique of paraglossal straight-blade laryngoscopy.[5, 47] Macintosh disagreed with the midline approach stating that this approach made '…the tongue bulge over the blade and obscure the view'.[5, 48]

Macintosh was not the first to design a curved blade or to comment that the blade's tip needed not be passed beyond the epiglottis or indeed directly lift it (in 1941, J. U. Human advised that the 'laryngoscope should be passed only until the epiglottis comes into view...' and that by lifting the tongue the blade would also lift the epiglottis from the posterior laryngeal wall).[49] Macintosh, however, was the first to suggest routinely placing the blade's tip in the vallecula and then indirectly lifting the epiglottis.[5, 50] Macintosh did not consider the shape or curve of the blade of primary importance, but it may often avoid trauma to the patient's upper teeth.[51]

## RECENT DEVELOPMENTS

Many variations of the curved bladed laryngoscopes have been described, most without data about their efficacy. For example, McCoy introduced a Macintosh-type laryngoscope with a hinged tip that flexes when a lever on the handle is depressed.[44]

Laryngoscopy has improved with the development of flexible fibreoptic cables enabling a much better visualization and illumination of the larynx for both direct and indirect laryngoscopy. The development of fibrescopes was first undertaken during the late 1950s for medical purposes.[1] In 1968, Kensuke Ikeda of Japan introduced flexible fibreoptic bronchoscopy into medical practice following the first successful fibreoptic intubation reported by Calder in 1967. [2, 52]

In recent years the development of a variety of indirect video-assisted laryngoscopes (videolaryngoscopes (VLS)) has brought us back to a modern way of indirect laryngoscopy. For almost 90 years since Magill designed his laryngoscope and more than 70 years from the introduction of Miller's and Macintosh's straight and curved laryngoscopy blades, laryngoscopy has essentially remained unchanged until the introduction in the 1990s of rigid fibreoptic endoscopy (Bullard Scope®[53], Wu Scope®[54], UpsherScope®[55]) and videolaryngoscopy in the 2000s.

In 1998, Weiss[13] modified DL by incorporating a fibreoptic bundle into the Macintosh blade. A Canadian surgeon, John Pacey, embedded a miniature video chip to a curved non-Macintosh blade,[56-58] while Berci and Kaplan added the specific DCI Camera Head, with distal light and image fibres (providing optimal illumination and image acquisition) to a standard Macintosh blade.[59, 60]

From 2000 onwards there has been a plethora of different indirect VLS developed. The VLS currently available can be roughly divided into two groups: channelled and non-channelled. The non-channelled devices can be divided in angulated and non-angulated (Table 1).

**Table 1:** Non-exhaustive overview of videolaryngoscopes

| Channelled | Non-channelled | |
|---|---|---|
| | Macintosh shaped | Angulated |
| Airway Scope® (Pentax, Tokyo, Japan) | Storz V-MAC® (Karl Storz, Tuttlingen, Germany) | Storz C-MAC D-blade® (Karl Storz, Tuttlingen, Germany) |
| Airtraq® (Prodol Meditec S.A., Vizcaya, Spain) | Storz C-MAC® (Karl Storz, Tuttlingen, Germany) | GlideScope Cobalt® (GlideScope, Verathon, WA, USA) |
| King Vision® (King Systems, Noblesville, IN, USA) | Coopdech® (Daiken Medical, Osaka, Japan) | GlideScope Ranger® (GlideScope, Verathon, WA, USA) |
| | McGrath MAC® (Aircraft Medical, Edinburgh, UK) | McGrath Series 5® (Aircraft Medical, Edinburgh, UK) |
| | Venner A.P. Advance (MAC blade)® (Venner Medical, Singapore, Republic of Singapore) | Venner A.P. Advance DAB (difficult airway blade)® (Venner Medical, Singapore, Republic of Singapore) |

There are many differences in the currently available VLS. Some other differences are: the level of evidence supporting their use and the method of insertion (along the floor of the mouth displacing the tongue to the left ('Macintosh like'), or over the centre of the tongue with no tongue displacement). VLS also differ in the method of display of the laryngeal view: some have an integrated camera that records images and displays them via a fibreoptic bundle attached video screen while others use an external video camera that is connected to the scope and an external video screen.[61]

VLS that are placed over the centre of the tongue and have an acute curvature ($60^0$) like the GlideScope don't allow a direct view of the larynx and a rigid, curved stylet is needed for intubation most of the time. The anaesthetist should be aware that the use of a rigid stylet might increase the risk of trauma to the palatal arch and other structures.[62, 63]

One of the advantages of videolaryngoscopy over DL is due to the position of the camera eye within a few centimetres from the glottis, whereby alignment of the oral, pharyngeal, and laryngeal axes is not necessary as in DL.[64] The advantages and disadvantages of VLS are listed in Table 2 and Table 3. However, these sited advantages and disadvantages are not applicable to all VLS.

**Table 2:** The advantages of videolaryngoscopy.[65-67]

| |
|---|
| • Better view of the glottis (less failed laryngoscopic view = Cormack and Lehane grade III-IV) |
| • Precise visual control |
| • Confirmation of tracheal intubation |
| • Able to record tracheal intubation |
| • Shorter intubation time for patients with both normal and difficult airways |
| • Greater success rate of intubation in difficult airways |
| • Good teaching tool – able to record anatomy |
| • Can be used as a diagnostic tool |
| • Easier placement of oral gastric and nasogastric tubes |
| • Better posture for intubation |
| • Those that are based on the Macintosh blade allow 2 views of the glottic inlet (direct and indirect) so if one view is obstructed by secretions then the intubator still has another option |

**Table 3:** Some disadvantages of videolaryngoscopy.[65-67]

| |
|---|
| • No correlation between laryngeal view and intubation difficulty |
| • Fogging of lens – defogging solution or a warm up time may be needed |
| • Good hand eye co-ordination is required for intubation |
| • Expensive |
| • Some are associated with increased morbidity due to: a decreased space between the blade and palato-pharyngeal wall; intubator viewing the screen instead of direct evaluation of where the tracheal tube is going |
| • Microchips, screens and cables are easily damaged |
| • View changed from 3D to 2D |
| • Some lack paediatric blades |

## CONCLUSION

After more than 2000 years we can conclude that airway management is still evolving.

Many centuries, wise men struggled to achieve a direct view of the glottis. In the 21st century, it seems that we are in some way back where it all started. Indeed, there are many published studies concerning different indirect VLS. However, the debate on which one is best is not over yet. Many studies lack substantial data showing that certain VLS are easier to use and offer a better view when compared to the 'gold standard' Macintosh bladed laryngoscope. In their editorial, Frerk and Lee plea for the practice of laryngoscopy to be evidence-based and suggest an organized system of evaluation and research be developed before a new device is introduced into clinical practice, similar to that for new drugs.[68] In the future situation, patient (anatomy, pathology) and operator (skills, circumstances) may be important factors in choosing a particular videolaryngoscope for laryngoscopy and intubation.

In airway management, obtaining the best possible view is probably the most important feature. After centuries of development and a multitude of efforts, we believe the end of the journey towards the best possible view isn't near yet.

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# Chapter 3

## Videolaryngoscopy versus direct laryngoscopy use by experienced anaesthetists in patients with known difficult airways: a systematic review and meta-analysis.

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## ABSTRACT

Airway management is a fundament of anaesthesia. Experienced anaesthetists can be confronted with difficult or failed tracheal intubations, exposing the patient to a plethora of potential complications. We performed a systematic review and meta-analysis to find out if the literature unanimously demonstrates the advantage of videolaryngoscopy by experienced anaesthetists when intubating patients with a known difficult airway.

We searched PUBMED, MEDLINE, EMBASE and the Cochrane central register of controlled trials up to January 1$^{st}$ 2017. Outcome parameters extracted from studies were first attempt success of tracheal intubation, time to successful intubation, number of intubation attempts, Cormack & Lehane grade, use of airway adjuncts (e.g. stylet, gum elastic bougie) and complications (e.g. mucosal and dental trauma)).

Nine studies, including 1329 patients, fulfilled the inclusion criteria. First attempt success was greater for all videolaryngoscopes [OR 0.34 (95% CI 0.18-0.66) $p = 0.001$]. Use of videolaryngoscopy was associated with a significant better view of the glottis as expressed by Cormack & Lehane grades (I and II versus III-IV both [OR 0.04 (95% CI 0.01-0.15) $p < 0.00001$]). Mucosal trauma occurred less with the use of videolaryngoscopy [OR 0.16 (95 CI 0.04-0.75) $p = 0.02$].

This systematic review and meta-analysis shows that videolaryngoscopy has added value for the experienced anaesthetist when confronted with a patient with a difficult airway. Its use results in more first-time success, improved view of the glottis and less mucosal trauma.

## INTRODUCTION

Airway management is the core business of any anaesthetist, with direct laryngoscopy (DL) being the technique used for the majority of tracheal intubations. However, difficult, delayed and failed intubation as well as 'can't intubate can't ventilate' (CICV – or can't intubate can't oxygenate (CICO)) still accounts for 39% of all events during anaesthesia.[1]

By the end of the twentieth century, videolaryngoscopes (VLS) were introduced, providing anaesthetists a new tool to manage the (difficult) airway.[2,3] Nonetheless, the use of a videolaryngoscope is no guarantee for success. The success of an intubation depends on multiple factors, e.g. 1. VLS: a) design [acute angled/Macintosh blade - channelled/non-channelled]; b) quality of the image on the monitor; c) illumination of the oropharynx/larynx; 2. patients: a) anatomy and innate/acquired abnormalities; b) operation indication and location; c) previous history of difficult intubation; d) previous radiotherapy or tumours of the oropharynx/larynx; f) elective/emergency intubation; 3. intubator: a) skills [junior/senior]; b) previous experience [manikin/patients]; c) background [anaesthesia, intensive care unit, prehospital].[4]

Experience of the healthcare provider is a factor that should not be underestimated. Like DL, videolaryngoscopy competencies grow with a learning curve.[5] Videolaryngoscopy comes with a fast learning curve[6], but it has to be taught and one should not use a videolaryngoscope for the first time when being confronted with a difficult intubation. A handicap, especially for experienced anaesthetists, being relatively inexperienced with videolaryngoscopy, can be the acutely angled or curved blade of a selection of VLS (e.g. GlideScope and McGrath). The experienced anaesthetist, familiar with the act of DL, will subconsciously try to bring the oral, pharyngeal and tracheal axes in one line.[7] Doing so could hamper the intubation when using a videolaryngoscope with an acutely angled blade.

Several studies have been conducted comparing the quality of videolaryngoscopy with DL. There are many clear advantages of videolaryngoscopy.[8,9] However, in our own clinical experience, improved laryngeal views do not always result in: a) an easy intubation; and b) a higher first and overall intubation success rate.[10] Is videolaryngoscopy superior to classic DL for patients with a known difficult airway when used by anaesthetists experienced with DL? If so, should DL be abandoned altogether for the intubation of patients with known difficult airways and should videolaryngoscopy become the new standard?

The aim of this manuscript was to execute a systematic review and meta-analysis to find out if the literature unanimously agrees in favour of the use of videolaryngoscopy by experienced anaesthetists when intubating patients with known difficult airways.

## METHODS

We consulted the preferred reporting items for systematic reviews and meta-analysis (PRISMA) guidelines for meta-analyses.[11]

### Search strategy

We searched PUBMED, EMBASE and the Cochrane central register of controlled trials up to January 1$^{st}$ 2017. We also considered published review articles and editorials as additional sources of information. Reference lists of selected articles were reviewed for other potentially relevant citations. The search syntax can be found in appendix A. In the protocol, we included trials comparing (classic) DL with VLS.

### Study selection and eligibility criteria

In the selection process, the titles and abstracts of all citations were screened by the authors (BP and EM) to identify potentially relevant studies. In a second step, the full texts of the respective publications were reviewed to assess whether the studies met the following inclusion criteria: randomized controlled trials, observational studies and cohort studies, concerning patients > 18 years of age, with suspected difficult airway, scheduled for elective surgery, requiring tracheal intubation by anaesthetists experienced with DL, comparing videolaryngoscopy with DL. Studies were excluded when they were not published in English. Studies reporting only intubation by videolaryngoscopy or DL were also excluded.

### Data collection process and data items

Relevant information from the articles, including baseline clinical characteristics of the study population and outcome measures, were extracted to a database. Outcome parameters extracted from the studies were success of intubation, time to successful intubation, number of intubation attempts, Cormack & Lehane (C&L) grade, use of adjuncts (e.g. stylet and gum elastic bougie) and complications (e.g. mucosal and dental trauma).

### Summary measures and synthesis of results

Data of the included studies were combined to calculate the pooled effect (odds ratio, OR) of videolaryngoscopy versus DL.[12] Continuous data (e.g. time to successful intubation) were described as means with its 95%-confidence interval.

Our primary result estimates of the average effect across studies are presented using 95% confidence intervals (CI). In case no event occurred in one of the two groups no statistical adjustment was made to calculate a relative risk with its confidence interval.

For our meta-analysis, we used the random effects model that primarily estimates the mean of a distribution of effects. By this approach, the weights of the individual studies are more balanced than in a fixed-effect model. It follows that smaller studies are assigned more relative weight, while larger studies weigh relatively less.[12] The difference in means was used to measure the absolute difference in means between the two groups for different outcome variables.

Heterogeneity among trials was quantified with Higgings' and Thompson's $I^2$. $I^2$ describes the percentage of total variation across studies that is due to heterogeneity rather than chance. A value of 0% indicates no observed heterogeneity, and larger values indicate increasing heterogeneity. An $I^2 > 50\%$ is considered to represent substantial heterogeneity.[13]

For all analyses, we used Review Manager (RevMan), Version 5.3, (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014), downloaded on January 11th - 2017 at www.tech.cochrane.org.



### Risk of bias

For assessing the risk of bias, we used a domain-based evaluation, in which assessments are made separately for different domains (e.g. selection bias, performance bias), recommended by the Cochrane Collaboration.[12] Owing to the small number of studies included in this analysis, we did not test for publication bias or small study effects.

## RESULTS

Our database searching revealed 173 articles, 8 articles were identified through other resources. We removed 130 duplicates and screened the titles and abstracts of 51 records for eligibility. Of these, 25 articles were excluded because of a lack of relevance. A total of 26 full-text articles were screened for eligibility, of which 17 were excluded. A total of 9 studies, including 1329 patients, fulfilled the predefined inclusion criteria (Figure 1).[14-22] The VLS used were GlideScope (3 studies)[18,20,21], C-MAC (2 studies)[14,19], Pentax AWS[15], McGrath [16], Airtraq[17], C-MAC D-Blade[20] and the Berci-Kaplan video laryngoscope[22] (all 1 study). One study compared the GlideScope and C-MAC D-Blade VLS to DL.[20]

### Baseline Characteristics

Baseline characteristics of patients are presented in Table 1.

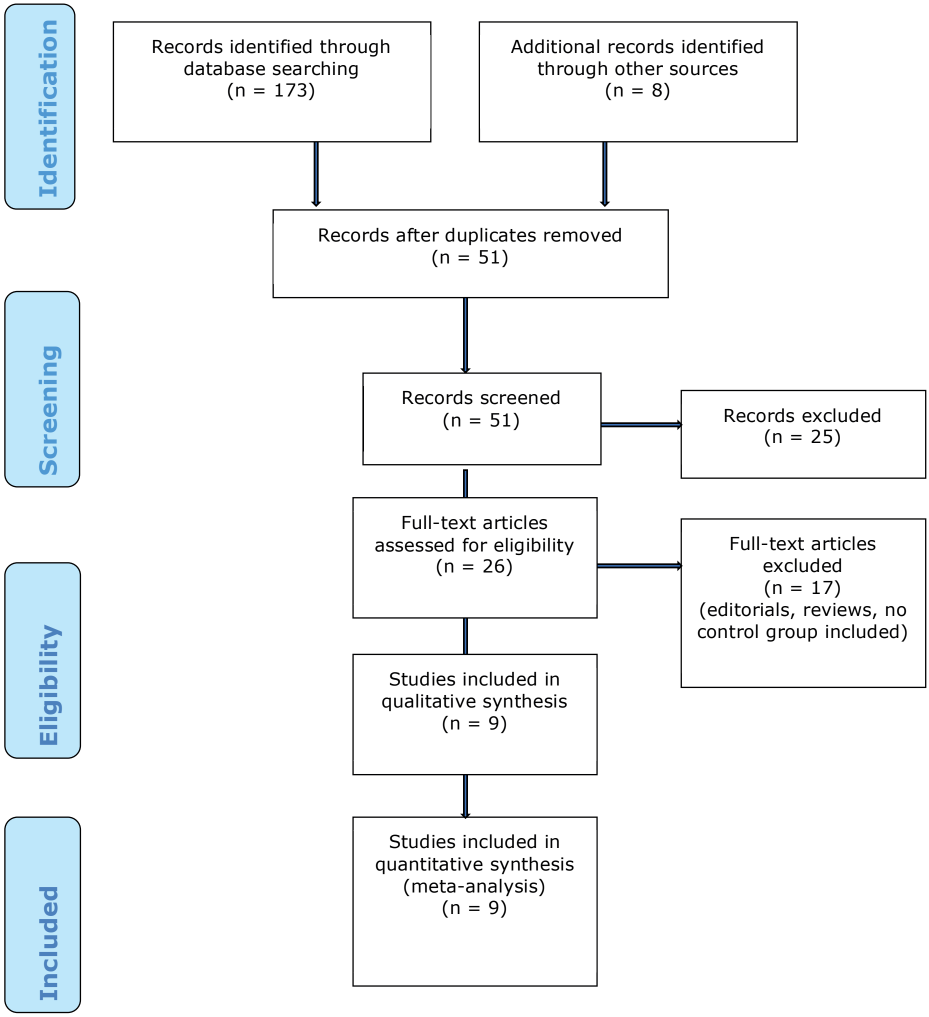


**Figure 3.1:** Flow diagram of study selection process (according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines)

## First attempt success of tracheal intubation (Figure 2)

The choice of videolaryngoscope or direct laryngoscope affected the first attempt success of intubation. First attempt success was greater for all VLS, 446 out of 468 attempts (95%) compared to 398 out of 461 (86%) for DL [OR 0.34 (95% CI 0.18-0.66) p = 0.001]. Since in the study by Serocki et al.[20] patients were intubated using both the classic laryngoscope and one of two VLS, this study is mentioned twice in Figure 2. Analysing only the studies evaluating the GlideScope videolaryngoscope showed a first attempt success of intubation of 68 out of 72 attempts (94%) for the GlideScope, compared to 57

**Table 1:** Baseline characteristics of patients

| Study | Device | Patients (n) | Age (years) | Sex (m/f) | Weight (kg) | Height (cm) | BMI (kg.m$^{-2}$) |
|---|---|---|---|---|---|---|---|
| Cavus | Direct | 50 | 49 [23-82] | 21/29 | 81 [60-179] | 170 [156-196] | 27 [20-63] |
| | C-MAC | 55 | 53 [20-79] | 49/51 | 79 [48-150] | 171 [150-193] | 27 [19-44] |
| Suzuki | | | | | | | $\underline{>30\ kg.m^{-2}}$ (n) |
| | PentaxAWS | 320 | 55 [18-90] | 163/157 | 59 [28-123] | 159 [135-187] | 42 |
| Ng | Direct | 40 | N/A | N/A | 87 ± 22.8 | 167 ± 11.0 | 32 ± 14.8 |
| | McGrath | 40 | | | 88 ± 23.9 | 166 ± 11.2 | 32 ± 8.3 |
| Maharaj | Direct | 20 | 50 ± 18.2 | 10/10 | N/A | N/A | 30 ± 6.8 |
| | Airtraq | 20 | 52 ± 14.6 | 8/12 | | | 29 ± 4.7 |
| Stroumpoulis* | | | | | | | $\underline{>35\ kg.m^{-2}}$ (n) |
| | All | 112 | 54 ± 13.4 | 60/52 | 74 ± 18.5 | 171 ± 10.0 | 9 |
| Aziz | Direct | 147 | 55 ± 14 | 74/75 | N/A | N/A | 34 ± 10 |
| | C-MAC | 149 | 55 ± 15 | 83/64 | | | 34 ± 10 |
| Serocki | Direct | 32 | 59 ± 16 | 16/16 | 76 ± 16 | 171 ± 9 | N/A |
| | GlideScope | 32 | 59 ± 13 | 24/8 | 81 ± 14 | 177 ± 11 | |
| | D-Blade | 32 | 51 ± 19 | 25/7 | 81 ± 17 | 176 ± 10 | |
| Liu | Direct | 40 | 60 ±15 | 22/18 | 68 ± 9 | 168 ± 9 | 22 ± 5 |
| | GlideScope | 40 | 60 ±16 | 22/18 | 72 ± 10 | 172 ± 8 | 23 ± 5 |
| Jungbauer | Direct | 100 | 54.2 [18-94] | N/A | 78.7 (19.4) | 172 (9) | N/A |
| | Kaplan-Berci | 100 | 56.8 [18-88] | | 83.2 (20.8) | 172 (10) | |

*Figures given as median[range] or median ± SD*

** No distinction between DL and VLS group*

3

**Table 1:** continued

| Study | Device | ASA (I/II/III/IV) | Interincisor- distance (cm) | Thyromental distance (cm) | Mallampati (I/II/III/IV) | History of difficult intubation (n) | Limited cervical motion (n) |
|---|---|---|---|---|---|---|---|
| Cavus | Direct | N/A | 5 ± 1 | 8.0 ± 2.0 | 16/20/13/1 | N/A | N/A |
| | C-MAC | | 5 ± 1 | 8.0 ± 3.0 | 21/50/28/1 | | |
| Suzuki | PentaxAWS | 133/146/41 | N/A | 7.4 ± 1.0 | 122/143/49/6 | N/A | N/A |
| Ng | Direct | N/A | N/A | N/A | 0/0/35/5 | N/A | N/A |
| | McGrath | | | | 0/0/38/2 | | |
| Maharaj | | | >4 / 3.1-4 / ≤3 | ≥6 / 4.1-6 / ≤4 | | | |
| | Direct | N/A | 1±5/8±40/11±55 | 2±10/12±60/6±30 | 0/1/15/4 | 10 | N/A |
| | Airtraq | | 1±5/9±45/10±50 | 1±5/9±45/10±50 | 1/2/13/4 | 9 | N/A |
| Stroumpoulis* | | | | < 6 cm | | | |
| | All | N/A | N/A | 7 | 42/28/30/12 | 3 | N/A |
| Aziz | | | | < 6 cm | | | |
| | Direct | 2/53/87/5 | N/A | 28 | N/A | 8 | 40 |
| | C-MAC | 3/60/80/6 | | 11 | | 7 | 40 |
| Serocki | | | <4 cm / ≥ 4 cm | < 6 cm / ≥ 6 cm | | | |
| | Direct | 2/19/11/0 | 10/22 | 8 ± 2.2 | 0/20/9/3 | N/A | 4 |
| | GlideScope | 0/21/11/0 | 9/23 | 7.4 ± 2.1 | 1/16/13/2 | | 4 |
| | D-Blade | 3/21/8/0 | 10/22 | 7.6 ± 1.4 | 1/16/11/4 | | 1 |
| Liu | All | N/A | N/A | N/A | N/A | N/A | N/A |
| Jungbauer | Direct | N/A | 3.7± 0.9 | 6.8 ±1.5 | 0/2/87/11 | N/A | N/A |
| | Kaplan-Berci | | 3.7 ± 0.9 | 7.0 ±1.4 | 0/1/76/23 | | |

*Figures given as median [range] or median ± SD*

** No distinction between DL and VLS group* out of 72 attempts (79%) for DL [OR 0.24 (95% CI 0.03-1.70) p=0.15]. Suzuki et al.[15] and Stroumpoulis et al.[18] only intubated patients using a videolaryngoscope, hence these studies are not incorporated in Figure 2.

| Study or Subgroup | Videolaryngoscopy Events | Videolaryngoscopy Total | Direct laryngoscopy Events | Direct laryngoscopy Total | Weight | Odds Ratio (Non-event) M-H, Random, 95% CI |
|---|---|---|---|---|---|---|
| Aziz 2012 | 138 | 149 | 124 | 147 | 35.7% | 0.43 [0.20, 0.92] |
| Cavus 2011 | 55 | 55 | 44 | 50 | 4.7% | 0.06 [0.00, 1.12] |
| Jungbauer 2009 | 99 | 100 | 92 | 100 | 8.5% | 0.12 [0.01, 0.95] |
| Ling Liu 2014 | 39 | 40 | 30 | 40 | 8.4% | 0.08 [0.01, 0.63] |
| Maharaj 2008 | 20 | 20 | 16 | 20 | 4.4% | 0.09 [0.00, 1.78] |
| Ng 2011 | 39 | 40 | 38 | 40 | 6.4% | 0.49 [0.04, 5.60] |
| Serocki 2013 | 27 | 32 | 27 | 32 | 17.4% | 1.00 [0.26, 3.86] |
| Serocki 2013 | 29 | 32 | 27 | 32 | 14.4% | 0.56 [0.12, 2.57] |
| **Total (95% CI)** | | **468** | | **461** | **100.0%** | **0.34 [0.18, 0.66]** |
| Total events | 446 | | 398 | | | |

Heterogeneity: $Tau^2 = 0.16$; $Chi^2 = 8.55$, df = 7 (P = 0.29); $I^2 = 18\%$
Test for overall effect: Z = 3.21 (P = 0.001)

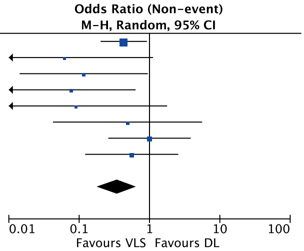


**Figure 3.2:** First attempt intubation success

## Time to successful tracheal intubation (Figure 3)

The mean time until successful intubation was 28 seconds (s) for VLS, compared to 37 s for DL. The study by Serocki et al.[20] is mentioned twice in Figure 3 because two VLS were analysed. Analyses were repeated including only the studies incorporating the Glide-Scope[18,20,21], showing a mean time to successful intubation of 30 s compared to 42 s for DL. Because of the extremely high level of statistical heterogeneity ($I^2$ = 97%) however, no effects estimate was presented for this outcome. The high level of heterogeneity could possibly be explained by the various time points at which individual studies measured time for intubation.

| Study or Subgroup | Videolaryngoscopy Mean | Videolaryngoscopy SD | Videolaryngoscopy Total | Direct laryngoscopy Mean | Direct laryngoscopy SD | Direct laryngoscopy Total | Weight | Mean Difference IV, Random, 95% CI |
|---|---|---|---|---|---|---|---|---|
| Aziz 2012 | 46 | 34.65 | 149 | 33 | 21.65 | 147 | 11.6% | 13.00 [6.43, 19.57] |
| Cavus 2011 | 16 | 16 | 37 | 11 | 14 | 50 | 11.7% | 5.00 [−1.45, 11.45] |
| Jungbauer 2009 | 40 | 31 | 100 | 70 | 77 | 100 | 9.2% | −30.00 [−46.27, −13.73] |
| Ling Liu 2014 | 29.8 | 22.3 | 40 | 68.8 | 26.6 | 40 | 10.7% | −39.00 [−49.76, −28.24] |
| Maharaj 2008 | 13.4 | 6.3 | 20 | 47.7 | 8.5 | 20 | 12.0% | −34.30 [−38.94, −29.66] |
| Ng 2011 | 43 | 43.77 | 40 | 35 | 40.65 | 40 | 8.6% | 8.00 [−10.51, 26.51] |
| Serocki 2013 | 10.8 | 4.3 | 32 | 13.2 | 6.3 | 32 | 12.2% | −2.40 [−5.04, 0.24] |
| Serocki 2013 | 12 | 5.8 | 32 | 13.2 | 6.3 | 32 | 12.1% | −1.20 [−4.17, 1.77] |
| Stroumpoulis 2009 | 44.9 | 19.7 | 112 | 44.9 | 19.7 | 112 | 11.9% | 0.00 [−5.16, 5.16] |
| **Total (95% CI)** | | | **562** | | | **573** | **100.0%** | **−8.70 [−18.60, 1.20]** |

Heterogeneity: $Tau^2 = 207.76$; $Chi^2 = 254.35$, df = 8 (P < 0.00001); $I^2 = 97\%$
Test for overall effect: Z = 1.72 (P = 0.08)

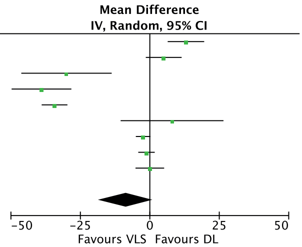


**Figure 3.3:** Time to successful intubation

## Cormack & Lehane grade (Figure 4)

For evaluation of the C&L grade, grades were divided in two groups: C&L grade I and II versus grade III and IV (Figure 4). Use of VLS resulted in more C&L grade I and II (897 out of 931 laryngoscopies (96.3%)) than when using DL (597 out of 929 direct laryngoscopies (64.3%)). When evaluating C&L grades III and IV, we found the difference between VLS and DL to be even greater. With DL, 332 out of 929 (35.7%) resulted in a C&L grade ≥ III, while with videolaryngoscopy this was the case in 34 of 931 (3.7%) laryngoscopies. C&L grade was scored in different ways by different investigators. This resulted in a very high level of statistical heterogeneity ($I^2 = 88\%$), and so no effects estimate was presented for this outcome.

| Study or Subgroup | Videolaryngoscopy Events | Videolaryngoscopy Total | Direct laryngoscopy Events | Direct laryngoscopy Total | Weight | Odds Ratio M–H, Random, 95% CI |
|---|---|---|---|---|---|---|
| Aziz 2012 | 10 | 149 | 28 | 147 | 16.1% | 0.31 [0.14, 0.66] |
| Jungbauer 2009 | 10 | 100 | 36 | 100 | 16.0% | 0.20 [0.09, 0.43] |
| Maharaj 2008 | 0 | 20 | 17 | 20 | 9.0% | 0.00 [0.00, 0.10] |
| Ng 2011 | 0 | 40 | 2 | 40 | 8.9% | 0.19 [0.01, 4.09] |
| Serocki 2013 | 0 | 95 | 81 | 95 | 9.6% | 0.00 [0.00, 0.02] |
| Serocki 2013 | 3 | 95 | 81 | 95 | 14.6% | 0.01 [0.00, 0.02] |
| Stroumpoulis 2009 | 11 | 112 | 41 | 112 | 16.1% | 0.19 [0.09, 0.39] |
| Suzuki 2008 | 0 | 320 | 46 | 320 | 9.7% | 0.01 [0.00, 0.15] |
| **Total (95% CI)** | | **931** | | **929** | **100.0%** | **0.04 [0.01, 0.15]** |
| Total events | 34 | | 332 | | | |

Heterogeneity: $Tau^2 = 2.70$; $Chi^2 = 57.02$, df = 7 ($P < 0.00001$); $I^2 = 88\%$
Test for overall effect: Z = 4.77 ($P < 0.00001$)

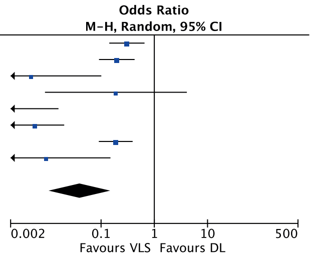


**Figure 3.4:** Cormack and Lehane grades III & IV

## Use of adjuncts (Figure 5)

Only four studies scored the use of adjuncts to aid intubation.[14,17,19,22] Adjuncts scored as being used were a bougie or stylet[17], gum elastic bougie[19,22], semi-flexible tube-guide[14], external laryngeal manipulation[19,22] and change in head position[22]. Adjuncts were not more frequently used with one of two techniques (DL 71 in 294 intubations (24.1%) versus VLS 52 in 358 intubations (14.5%)). Because of the high level of statistical heterogeneity ($I^2 = 68\%$), no effects estimate was presented for this outcome.

| Study or Subgroup | Videolaryngoscopy Events | Videolaryngoscopy Total | Direct laryngoscopy Events | Direct laryngoscopy Total | Weight | Odds Ratio M–H, Random, 95% CI |
|---|---|---|---|---|---|---|
| Aziz 2012 | 33 | 138 | 46 | 124 | 39.2% | 0.53 [0.31, 0.91] |
| Cavus 2011 | 12 | 100 | 1 | 50 | 17.2% | 6.68 [0.84, 52.94] |
| Jungbauer 2009 | 7 | 100 | 16 | 100 | 33.0% | 0.40 [0.15, 1.01] |
| Maharaj 2008 | 0 | 20 | 8 | 20 | 10.7% | 0.04 [0.00, 0.68] |
| **Total (95% CI)** | | **358** | | **294** | **100.0%** | **0.56 [0.19, 1.69]** |
| Total events | 52 | | 71 | | | |

Heterogeneity: $Tau^2 = 0.74$; $Chi^2 = 9.40$, df = 3 ($P = 0.02$); $I^2 = 68\%$
Test for overall effect: Z = 1.03 ($P = 0.30$)

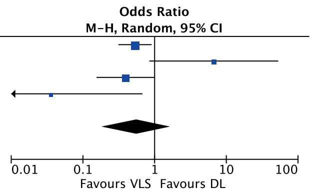


**Figure 3.5:** Use of airway adjuncts

## Number of intubation attempts (>1) (Figure 6)

Number of intubation attempts (>1) was described in 5 studies.[14,16,17,20,21] Because Serocki et al.[20] described two different types of VLS, this study is mentioned twice in Figure 6. Users needed more than 1 attempt when using DL in 10.3% of cases (35 out of 340); with the VLS in 9.0% of cases (31 out of 345). Attempts were defined and scored differently, resulting in a high level of statistical heterogeneity ($I^2 = 73\%$). Therefore, no effects estimate was presented for this outcome.

| Study or Subgroup | Videolaryngoscopy Events | Videolaryngoscopy Total | Direct laryngoscopy Events | Direct laryngoscopy Total | Weight | Odds Ratio M-H, Random, 95% CI |
|---|---|---|---|---|---|---|
| Cavus 2011 | 14 | 55 | 2 | 50 | 17.3% | 8.20 [1.76, 38.19] |
| Ling Liu 2014 | 1 | 40 | 10 | 40 | 14.1% | 0.08 [0.01, 0.63] |
| Maharaj 2008 | 1 | 20 | 7 | 20 | 13.6% | 0.10 [0.01, 0.89] |
| Ng 2011 | 8 | 40 | 6 | 40 | 19.5% | 1.42 [0.44, 4.53] |
| Serocki 2013 | 2 | 95 | 5 | 95 | 16.6% | 0.39 [0.07, 2.05] |
| Serocki 2013 | 5 | 95 | 5 | 95 | 18.9% | 1.00 [0.28, 3.57] |
| **Total (95% CI)** | | **345** | | **340** | **100.0%** | **0.67 [0.19, 2.34]** |
| Total events | 31 | | 35 | | | |

Heterogeneity: Tau² = 1.73; Chi² = 18.64, df = 5 (P = 0.002); I² = 73%
Test for overall effect: Z = 0.63 (P = 0.53)

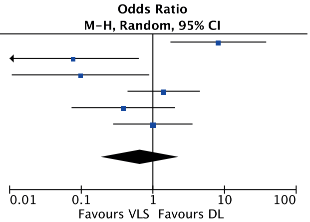


**Figure 3.6:** Number of intubation attempts (>1)

## Complications (Figures 7 & 8)

Three studies reported dental trauma (Figure 7).[17,18,20] More trauma was reported with DL (5 out of 299 patients) compared to VLS (1 in 301 patients). The definition of dental complications and the manner in which they were recorded differed greatly, resulting in a high level of statistical heterogeneity ($I^2 = 63\%$), and so no effects estimate was presented for this outcome. Concerning mucosal trauma (Figure 8), the difference between VLS and DL did reach significance. Mucosal trauma occurred in 5 out of 249 patients when VLS were used, while 31 out of 247 patients in the DL group experienced such trauma [OR 0.16 (95 CI 0.04-0.75) p = 0.02].

| Study or Subgroup | Videolaryngoscopy Events | Videolaryngoscopy Total | Direct laryngoscopy Events | Direct laryngoscopy Total | Weight | Odds Ratio M-H, Random, 95% CI |
|---|---|---|---|---|---|---|
| Aziz 2012 | 1 | 149 | 0 | 147 | 48.3% | 2.98 [0.12, 73.74] |
| Ling Liu 2014 | 0 | 40 | 5 | 40 | 51.7% | 0.08 [0.00, 1.49] |
| Stroumpoulis 2009 | 0 | 112 | 0 | 112 | | Not estimable |
| **Total (95% CI)** | | **301** | | **299** | **100.0%** | **0.46 [0.01, 16.45]** |
| Total events | 1 | | 5 | | | |

Heterogeneity: Tau² = 4.22; Chi² = 2.72, df = 1 (P = 0.10); I² = 63%
Test for overall effect: Z = 0.43 (P = 0.67)

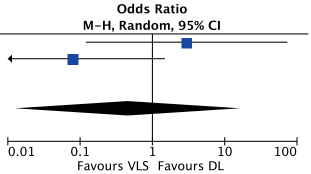


**Figure 3.7:** Dental complications

| Study or Subgroup | Videolaryngoscopy Events | Videolaryngoscopy Total | Direct laryngoscopy Events | Direct laryngoscopy Total | Weight | Odds Ratio M-H, Random, 95% CI |
|---|---|---|---|---|---|---|
| Aziz 2012 | 1 | 149 | 0 | 147 | 16.7% | 2.98 [0.12, 73.74] |
| Ling Liu 2014 | 4 | 40 | 20 | 40 | 46.6% | 0.11 [0.03, 0.37] |
| Maharaj 2008 | 0 | 20 | 9 | 20 | 19.0% | 0.03 [0.00, 0.56] |
| Ng 2011 | 0 | 40 | 2 | 40 | 17.8% | 0.19 [0.01, 4.09] |
| **Total (95% CI)** | | **249** | | **247** | **100.0%** | **0.16 [0.04, 0.75]** |
| Total events | 5 | | 31 | | | |

Heterogeneity: Tau² = 0.90; Chi² = 4.75, df = 3 (P = 0.19); I² = 37%
Test for overall effect: Z = 2.34 (P = 0.02)

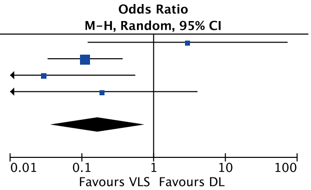


**Figure 3.8:** Mucosal trauma

## DISCUSSION

In this systematic review and meta-analysis, videolaryngoscopy used by experienced anaesthetists was compared to DL for patients with a known difficult airway. The analysis of 9 studies showed that videolaryngoscopy was associated with greater success of first intubation attempt, even for anaesthetists experienced with DL.

A first attempt success difference of 9% may not seem much. The risk of complications however, increases when more intubation attempts are made.[23] Repeating the attempt at tracheal intubation increases the risk of progression to a CICV/CICO situation[1] and the American Society of Anesthesiologists' Closed Claims Project (ASACCP) analysis suggested an increase in death and brain damage in such cases.[24] When direct laryngoscopy is unsuccessful, further attempts with the same technique have a close to 80% failure rate while alternative techniques (e.g. videolaryngoscopy) are more successful.[23] The Difficult Airway Society (DAS) guidelines are very clear about the importance of first-time success. It is essential to maximise the first attempt success rate.[1,25-27] Reserving the use of a videolaryngoscope for the second attempt, wastes the first attempt and subsequently makes the second one more difficult. Device performance differs between users and devices and this should be appreciated.[28] As stated by Marshall and Pandit in their editorial, hospitals will probably need to provide a range of VLS, to give their anaesthetists the option to choose the most suitable device. The available range will be restricted for reasons of cost, but anaesthetic departments may be judged harshly when a critical airway incident arises and is analysed using these new guidelines.[29]

In contrast to our results, Lewis et al.[30] found a reduction in the number of failed intubations in their recent Cochrane review, but not in the number of intubation attempts. Their review differs as that it was not limited to patients with a suspected difficult airway, and did include patients with a simulated difficult airway. Griesdale et al.[31] found a greater success of first intubation attempt, although this was confined to nonexpert operators only.

The use of VLS was not associated with a shorter time to successful intubation. This is in accordance with Griesdale et al.; they only found a faster time to intubation when the GlideScope was used by nonexpert users.[31] A shorter time to successful intubation can be of major importance when the initial time is long and thus associated with complications (e.g. hypoxia). If, however, the initial time is already short, an even shorter time can be of little clinical significance and should not come at the cost of (other) complications, e.g. dental or mucosal trauma.

In our meta-analysis, videolaryngoscopy resulted in an improved view of the glottis. The number of laryngoscopies resulting in a C&L grade III or IV was less when using videolaryngoscopy in general and VLS with acutely angled blades in particular (e.g. Pentax AWS, Airtraq, GlideScope and C-MAC D-Blade).[15,17,20] As mentioned before, VLS with an acutely angled blade ask for another technique of intubation; the shape of the blade follows the natural anatomy of the oral cavity and the camera at the tip of the blade brings the point of view of the operator very close to the glottis. Different factors make that a perfect view does not always result in a smooth intubation.[16] Only three studies included in this meta-analysis evaluated Macintosh shaped VLS.[14,19,22] Based on only these three studies, it is difficult to subtract anything comparing VLS with Macintosh shaped blades to VLS with acutely angled blades. It seems that the best view of the glottis is not automatically associated with the highest rate of first intubation success.[15,20]

With videolaryngoscopy, despite a perfect view of the glottis, it still can be difficult to correctly place the tracheal tube (TT). Operator hand-eye coordination skills play an important role.[28] Studies evaluating training of laparoscopic skills for surgeons showed that repeated practice is of utmost importance.[32] There is no reason to suspect this to be different for anaesthetists. The design of the TT too influences tracheal intubation. The TT is designed to follow a direct route towards the glottis with DL. With acutely angled VLS, the TT has to follow a more indirect route to the glottis. This problem can easily be overcome by the use of a stylet, as advocated by many manufacturers. The standard use of a stylet may seem of minor importance, however, the user should always be aware that a rigid, styletted TT may pose the patient at risk of mucosal trauma, especially when the videolaryngoscope is a bulky device and there is little room to manoeuvre next to it.[33,34]

A major strength of the current meta-analysis is that it shows that videolaryngoscopy has an added value for experienced anaesthetists. In our own experience, anaesthetists familiar with DL sometimes seem to be somewhat reluctant to use VLS. Old habits do not change easily.[35] Indeed, experience with DL does not equate to skill with videolaryngoscopy and being skilled in the use of one videolaryngoscope does not automatically make one skilled with all VLS.[3] Earlier, Cooper et al. pointed out that it was more difficult to teach videolaryngoscopy to experienced Macintosh users than to novices.[36] Cortellazzi et al. showed in their study that videolaryngoscopy is a complex skill that requires extensive practice to achieve expertise, even in those trained in DL.[37] This implies that, because videolaryngoscopy has added value for experienced anaesthetists, they too should practice extensively and should not rely on their expertise with DL. This is substantiated by the results of Caldiroli et al., showing that proficiency in DL cannot be equated with proficiency in videolaryngoscopy, and that different methods of training and assessment may be required.[38]

Recently, the Cochrane review by Lewis et al. compared DL to videolaryngoscopy for tracheal intubation.[30] We are aware of the similarities between their review and the present one. However, there are some important differences; a) we reviewed studies concerning patients with a suspected difficult airway, the Cochrane review included studies using videolaryngoscopy for tracheal intubation *in general*; b) in our review, we only included cross-over studies analysing the intubation of adults using a videolaryngoscope and a classic direct laryngoscope; c) all studies regarding a simulated difficult airway were excluded, in contrast to the Cochrane review; and d) we specifically addressed anaesthetists experienced with DL when confronted with a suspected difficult airway. This approach was chosen to find out if the added value of videolaryngoscopy is also present for experienced anaesthetists, seeming maybe somewhat reluctant toward videolaryngoscopy.

The ideal videolaryngoscope combines the benefits of conventional Macintosh blade DL and videolaryngoscopy in one device, taking advantage of the experience gained over the years, making the concept of the laryngoscopy technique intuitively familiar to providers.[19] We were interested in the possible added value of VLS for a group of experienced DL users. The mutual comparison of different VLS, like the one by Ng et al.[39], has added value in the extension of this study so that VLS can be compared mutually.

This systematic review and meta-analysis has limitations. First, anaesthetists were not blinded to the device, which could have led to altered performance as a result of the Hawthorne effect (individuals know they are being observed and therefore change their behaviour).[40] Second, analysis of time until successful intubation was complicated by different factors: a) not all patients included were actually intubated using the whole range of VLS included in the study[15,18]; and b) different studies use different definitions to start and end time recording (e.g. start at induction[18] versus touching of the tracheal tube[14,20]) resulting in an extremely high level of heterogeneity. Third, studies evaluating the use of VLS in patients with a simulated difficult airway were excluded. Simulating a difficult airway results in a cohort of patients with similar types of difficult airways. These cohorts provide information about the performance of a device in a single kind of difficult airway, e.g. a difficult airway caused by the appliance of a cervical collar resulting in limited neck movement and/or mouth opening. As stated by Kleine-Brueggeney et al.[41] the performance of the videolaryngoscope depends on the exact circumstances of the difficult airway and the optimal videolaryngoscope might differ for various types of difficult airway situations. Their study helps the professional in choosing a device for a patient with limited neck movement and/or mouth opening, but will be less helpful in picking the right device for e.g. an obese patient with a short thyromental distance.[42] Fourth, two studies[14,15] did not limit inclusion to patients with suspected difficult airways. Considering that they are cross-over studies directly comparing DL to videolaryngoscopy and did not exclude patients with suspected difficult airways, comparison between DL and videolaryngoscopy for patients with a suspected difficult airway is still possible.

Clinical signs of a difficult airway are not clear cut and overlap with those of a normal airway. Real difficult airways are very rare and no predictive test will ever fulfil all the thresholds (sensitivity, specificity etc.).[43] The 'difficult airway' should be regarded as a syndrome, composed of very many individual 'rare diseases'.[43] Fifth, although we did not correct for multiple testing, we did analyse multiple outcome measures. Sixth, there may have been differences between studies concerning operator characteristics regarding pre-existing device preference and previous experience that we were unable to evaluate from the available information. Seventh, the C&L grading system was used to analyse the laryngoscopic view during videolaryngoscopy in all included studies. The value of the C&L grading system however, is questionable in the setting of videolaryngoscopy due to the low inter-rater reliability, both clinically and in research.[28,44] Alternatives would be the Fremantle score, but this remains unused in worldwide clinical practice and the POGO score, which in our opinion has limited value in videolaryngoscopy, since the amount of glottis opening that can be seen is in videolaryngoscopy not automatically linked to the ease and success of intubation. This is in contrast to DL, where due to the direct line of sight, the worse the view, the more likely it is that intubation is difficult.[45,46] Also, in seven of the nine studies included in the current review, DL was performed using a classic direct laryngoscope with a Macintosh blade. Two studies however, either used the Henderson straight blade[16], or the type of DL blade was not specified.[21] Finally, publication bias may have been present, meaning that small studies favouring DL were not published. Risk of bias is presented in Appendix B.

In conclusion, this systematic review and meta-analysis provides evidence of the added value of videolaryngoscopy for experienced anaesthetists when confronted with a patient with a difficult airway. The use of videolaryngoscopy results in an improved view of the glottis, more first-time intubation success and less mucosal trauma. This review underlines the added value of videolaryngoscopy. It should become standard of care for the management of difficult airways and maybe even the initial approach to every intubation. The anaesthesia community should embrace videolaryngoscopy the same way it embraced ultrasound for central venous catheterisation setting up guidelines, demanding training and practice and developing a curriculum defining basic knowledge and skills.[47] Not only for the younger, less experienced professionals, but for all. Guidelines not only help guide clinicians, but come with the opportunity to improve standards, to ensure equipment is available as well as training for the skills and processes required.[29] Further research should focus on comparing the whole range of available VLS, so that in the future recommendations can be made about which device should be used for which patient, taking into account the patient's condition and the background and experience of the videolaryngoscope user.

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## APPENDIX A

Videolaryngoscopy versus direct laryngoscopy use by experienced anaesthetists in patients with known difficult airways: a systematic review and meta-analysis.

### Protocol

*PICOS*
Population: patients > 18 years of age, with known difficult airway, scheduled for elective surgery, requiring tracheal intubation by experienced anaesthetists.

Intervention: Tracheal intubation by direct laryngoscopy

Comparison: Tracheal intubation by videolaryngoscopy

Outcome: Success of intubation, time to successful intubation, number of attempts, Cormack & Lehane grade, use of adjuncts (e.g. stylet, gum elastic bougie and optimisation manoeuvres) and complications (e.g. oromucosal and dental trauma)).

Study design: Randomized controlled trials, observational studies and cohort studies
Search in: Pubmed, EMBASE, Medline, Cochrane central register of controlled trials

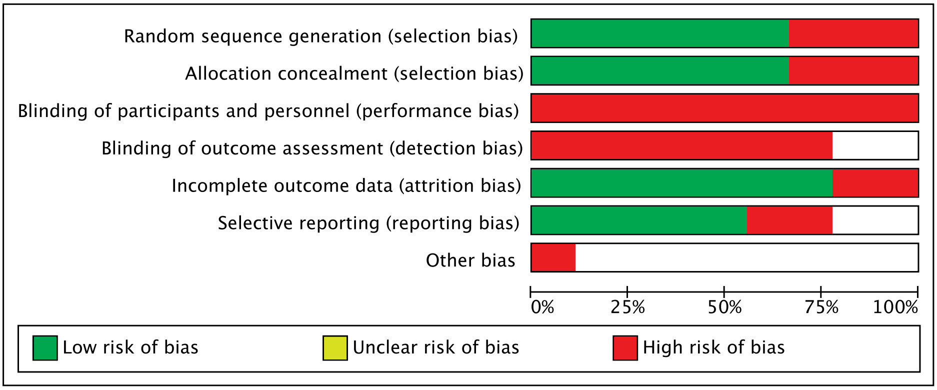
Search criteria:
1. Anesthesia
2. Anaesthesia
3. Anesthetic
4. Anaesthetic
5. General
6. Airway management
7. Airway control
8. Orotracheal intubation
9. Tracheal intubation
10. Difficult airway
11. Videolaryngoscope
12. Videolaryngoscopy
13. Macintosh / V-MAC / C-MAC / C-MAC D-Blade / Coopdech / McGrath / McGrath MAC/ GlideScope / Pentax / Airtraq / Venner / Kingvision
14. 1 OR 2 OR 3 AND 4 AND 5 OR 6 AND 7 OR 8 AND 9 AND 10 OR 11 AND 12

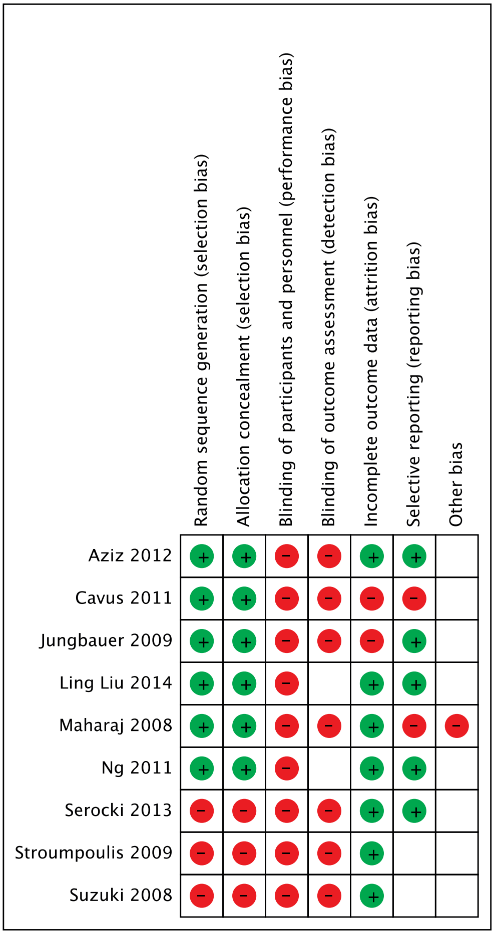
Eligibility: screening of title and abstract by BP and EM

Study selection and endpoints

- Patients > 18 years of age, with known difficult airway, scheduled for elective surgery, requiring tracheal intubation by experienced anaesthetists
- Studies published in English language
- Study period until January 2017
- Provision of at least two of the following outcome data:
    - Success of intubation
    - Time to successful intubation
    - Number of attempts Cormack & Lehane grade
    - Use of adjuncts (e.g. stylet, gum elastic bougie and optimisation manoeuvres)
    - Complications (e.g. oromucosal and dental trauma).

## APPENDIX B


Random sequence generation (selection bias)
Allocation concealment (selection bias)
Blinding of participants and personnel (performance bias)
Blinding of outcome assessment (detection bias)
Incomplete outcome data (attrition bias)
Selective reporting (reporting bias)
Other bias
0%
25%
50%
75%
100%
Low risk of bias
Unclear risk of bias
High risk of bias


Random sequence generation (selection bias)
Allocation concealment (selection bias)
Blinding of participants and personnel (performance bias)
Blinding of outcome assessment (detection bias)
Incomplete outcome data (attrition bias)
Selective reporting (reporting bias)
Other bias
Aziz 2012
Cavus 2011
Jungbauer 2009
Ling Liu 2014
Maharaj 2008
Ng 2011
Serocki 2013
Stroumpoulis 2009
Suzuki 2008

# Chapter 4

## Comparison of seven videolaryngoscopes with the Macintosh laryngoscope in manikins by experienced and novice personnel

Pieters BM, Wilbers NE, Huijzer M, Winkens B, van Zundert AA.

Anaesthesia. 2016; 71: 556-64.

## ABSTRACT

Videolaryngoscopy is often reserved for 'anticipated' difficult airways, but thereby can result in a higher overall rate of complications. We observed 65 anaesthetists, 67 residents in anaesthesia, 56 paramedics and 65 medical students, intubating the trachea of a standardised manikin model with a normal airway using eight devices: Macintosh classic laryngoscope, Airtraq®, Storz C-MAC®, Coopdech VLP-100®, Storz C-MAC D-Blade®, GlideScope Cobalt®, McGrath Series 5® and Pentax AWS® in random order. Time to and proportion of successful intubation, complications and user satisfaction were compared. All groups were fastest using devices with a Macintosh-type blade. All groups needed significantly more attempts using the Airtraq and Pentax AWS (all $p < 0.05$). Devices with a Macintosh-type blade (classic laryngoscope and C-MAC) scored highest in user satisfaction. Our results underline the importance of variability in device performance across individuals and staff groups, which have important implications for which devices hospital providers should rationally purchase.

## INTRODUCTION

Good airway management can be lifesaving. 'Complexity factors' (e.g. circumstances, patients' characteristics, background and experience of the healthcare provider) are highly variable and influence the difficulty of airway management.[1] Considerable experience is required before one becomes proficient in direct laryngoscopy (DL) and tracheal intubation.[2] In most situations, having an airway management expert at the bedside for every tracheal intubation is not feasible and airway management must be delivered by practitioners from different specialty backgrounds. The incidence of difficult or failed tracheal intubation is up to ~15% outside the operating theatre, compared with up to ~9% in the elective theatre setting. Moreover, outside the operating theatre, it is more likely to lead to significant morbidity and mortality.[3,4]



Videolaryngoscopes (VLS) are often seen as rescue devices. Yet, indirect videolaryngoscopy has proven advantageous over DL using a classic Macintosh blade.[5,6] But VLS differ and cannot be seen as a single entity. Similar to DL, considerable experience is necessary.[7] The transferability of skills between different types of VLS and the level of adequate training has yet to be established.

Current VLS may be superior for difficult airways, but may increase the risk in routine tracheal intubations.[8] For a videolaryngoscope to be acceptable to clinicians for all forms of practice, it should offer advantages in difficult tracheal intubations while not jeopardising normal airway tracheal intubations.[8,9]

With the current range of indirect VLS available, it can be difficult to choose the most suitable videolaryngoscope for specific situations, patients or laryngoscopists.

The aim of this study is to give an indication on which device would be most suitable for which healthcare provider. We compared the time to successful tracheal intubation and several other factors which can affect tracheal intubation, when anaesthetists, residents in anaesthesia, paramedics and medical students intubate a standardised manikin model with a normal airway. Our hypothesis was that groups may perform differently for any given device, and also that devices may perform differently across the groups.

## METHODS

After obtaining Institutional Review Board approval at Maastricht University Medical Centre (MUMC; registration MEC 10-5-059), anaesthetists, residents in anaesthesia, paramedics and medical students were recruited from the MUMC, Catharina Hospital Eindhoven, University Medical Centre Utrecht and Regional Ambulance Service Limburg Noord between January 2011 and November 2012. All participants were volunteers, who could choose not to participate, withdraw at any time, and could not be identified from the data collected. Data were collected on paper forms and entered onto an SPSS spreadsheet. Only investigators had access to the data, which are stored in a deidentified form.

We used an Airway Trainer™ manikin (Laerdal Stavanger, Norway); a study by Jordan et al. using this manikin commented on the good anatomical proportions of the oral cavity.[10]

Before the beginning of the trial, all participants received a standardised, 5 min demonstration by one of the investigators (BP, NW or MH) of the classic Macintosh laryngoscope and the different VLS and the use of optimisation manoeuvres (readjustment of head position, application of external laryngeal pressure and the use of a stylet). Practicing with the devices before the attempts was not allowed.

Each participant was asked to attempt tracheal intubation with each device in randomised order using the same normal airway scenario in the supine position. Photographs of the Cormack and Lehane (C&L) grades in the manikin were displayed next to the manikin as a reference. A cuffed tracheal tube (TT) (Mallinckrodt™; Covidien, Dublin, Ireland) with 7.5 mm internal diameter was used for all attempts.

The devices used for the study were: (a) a classic Macintosh laryngoscope (blade 3 (Karl Storz, Tuttlingen, Germany)); (b) Airtraq® (size 3 (Prodol, Vizcaya, Spain)); (c) Storz C-MAC® (Macintosh blade 3, 8402 ZX monitor (Karl Storz)); (d) Coopdech VLP-100® (BMAC-003 blade (Daiken Medical Co, Osaka, Japan)); (e) Storz C-MAC D-blade® (8402 ZX monitor (Karl Storz)); (f) GlideScope Cobalt® (blade 3 (Verathon Inc, Bothell, WA, USA)); (g) McGrath Series 5® (blade middle setting (Aircraft Medical, Edinburgh, UK)); and (h) Pentax Airway Scope® (Pentax Corporation, Tokyo, Japan); (Figure 1). All devices were property of the department or one of the investigators (AVZ).

It was left to the judgement of the participant whether or not they wanted to use a stylet. With the GlideScope, both rigid (GlideRite®; Verathon Inc) and malleable (Satin Slip®; Mallinckrodt, St. Louis, MO, USA) stylets have been proven to be equally effective.[11] Both stylets were available and participants were offered a choice of stylet when requested. When the participant chose to use a stylet, the stylet was placed within the tube from the start to shape the TT to the predesired form. As the Pentax AWS and the Airtraq have an integral guidance channel for the TT, participants were instructed that a stylet could not be used with either of these two devices.

Participants used each of the eight different devices in a randomised order. Both participants and investigators were blinded to device order. Eight closed envelopes were used, each containing the name of one of the devices. The order of the devices used was determined for each participant separately by selecting these eight envelopes, one at a time. Demographic data collected included participants' clinical position and the, by the participant, estimated (by each individual) number of previous clinical tracheal intubations with each device.


**Figure 4.1:** Different (video) laryngoscopes

A) Classic Macintosh laryngoscope (blade 3 (Karl Storz, Tuttlingen, Germany, www.karlstorz.com))
B) Airtraq® (size 3 (Prodol, Vizcaya, Spain, www.airtraq.com))
C) Storz C-MAC® (Macintosh blade 3, 8402 ZX monitor (Karl Storz, Tuttlingen, Germany, www.karlstorz.com))
D) Storz C-MAC, D-blade® (8402 ZX monitor (Karl Storz, Tuttlingen, Germany, www.karlstorz.com))
E) Coopdech VLP-100® (BMAC-003 blade (Daiken Medical Co, Osaka, Japan, www.daiken-iki.co.jp))
F) GlideScope Cobalt® (blade 3 (Verathon Inc, Bothell, WA, USA, www.verathon.com))
G) McGrath Series 5® (blade middle setting (Aircraft Medical, Edinburgh, UK, www.aircraftmedical.com))
H) Pentax Airway Scope® (Pentax Corporation, Tokyo Japan, www.airway-scope.com)

The primary outcome was the time to successful tracheal intubation. The investigator started timing as soon as the blade of the scope was positioned between the teeth of the manikin. The time until the best view of the glottis was achieved (marked as picking up of the TT (or touching the TT in case of the Airtraq and Pentax AWS)) and success of tracheal intubation was also noted. Timing ended when the participant declared the trachea to be intubated. Tracheal intubations that took > 180 s were classified as unsuccessful. Failed tracheal intubation was also defined as oesophageal intubation (not recognised by the participant) and tracheal intubations that required > three attempts. When the participant did recognise the intubation as being oesophageal, it was counted as one attempt instead of an unsuccessful intubation. If, however, the participant opted against a second or third attempt after a failed attempt on the basis that further attempts would be futile, the tracheal intubation was registered as failed.

Secondary end-points included: the number of tracheal intubation attempts; the number of optimisation manoeuvres to aid tracheal intubation; the C&L grade scored by the participant and the number of audible click sounds from contact of the (video) laryngoscope with the teeth of the manikin: this was recorded as a method of evaluation of dental trauma.

At the end of the study, each participant was asked to rank all devices on the basis of satisfaction, using a chart (1–8, very satisfactory – would definitively purchase this device – to not satisfactory at all – would never purchase this device).[12]

Based on the previous studies, taking into account the larger amount of devices used, we decided to perform an explorative study, including 65 participants per group.[9] The Friedman test was performed as non-parametric alternative to repeated measures ANOVA to analyse the difference in time until best view of the glottis and time until successful intubation between devices for each group of participants separately.[13] In addition, Wilcoxon signed-rank tests were used to assess pairwise differences between devices. On the other hand, the post-hoc Mann–Whitney U-test was used to compare groups. Differences between groups in rate of successful tracheal intubation were analysed using a Chi-squared test, whereas differences between devices were analysed using the McNemar test.

For the secondary end-points, the Wilcoxon signed-ranked test was used when comparing devices within a group. When comparing groups for the same device, the Chi-squared test was used. A $p \leq 0.05$ was considered statistically significant.

All analyses were performed using SPSS (IBM SPSS 22; IBM Corporation, Armonk, NY, USA).

## RESULTS

A total of 253 participants (65 anaesthetists, 67 residents in anaesthesia, 56 paramedics and 65 medical students) completed the study. Their levels of experience with the different devices are shown in detail in Table 1.

**Table 1:** Self-reported estimates of previous experience per device (uses on patients). Data are reported as numbers, median (IQR [range]).

| Device | Anaesthetists | Residents | Medical Students | Paramedics |
|---|---|---|---|---|
| Classic Macintosh | 6000 (6378-8847 [600-31400]) | 500 (325-492 [10-1000]) | 0 (0-2 [0-12]) | 50 (57-78 [0-150]) |
| Airtraq | 0 (0-3 [0-60]) | 0 (0-0 [0-0]) | 0 (0-0 [0-0]) | 0 (0-3 [0-50]) |
| C-MAC | 0 (0-49 [0-1000]) | 0 (0-8 [0-100]) | 0 (0-0 [0-1]) | 0 (0-0 [0-0]) |
| Coopdech | 0 (0-5 [0-100]) | 0 (0-0 [0-0]) | 0 (0-0 [0-0]) | 0 (0-0 [0-0]) |
| C-MAC D-Blade | 0 (0-0 [0-0]) | 0 (0-0 [0-0]) | 0 (0-0 [0-0]) | 0 (0-0 [0-0]) |
| GlideScope | 0 (0-50 [0-800]) | 0 (2-7 [0-80]) | 0 (0-0 [0-0]) | 0 (0-0 [0-3]) |
| McGrath | 0 (0-24 [0-500]) | 0 (0-5 [0-80]) | 0 (0-0 [0-0]) | 0 (0-0 [0-0]) |
| Pentax AWS | 0 (0-5 [0-75]) | 0 (0-0 [0-5]) | 0 (0-0 [0-0]) | 0 (0-2 [0-30]) |



The times until the best view of the glottis was achieved are graphically displayed in Table 2. All participants, except paramedics, took significantly longer to achieve the best view of the glottis when using the GlideScope (anaesthetists median (inter quartile range (IQR) [range]) 12 (11–18 [0–73]) s; residents 15 (15–22 [0–78]) s; medical students 15 (15–26 [0–87]) s; $p < 0.017$ vs other devices). Medical students also took significantly longer than other groups using the classic Macintosh laryngoscope (21 (20–31 [0–78]) s; $p < 0.001$ vs other groups).

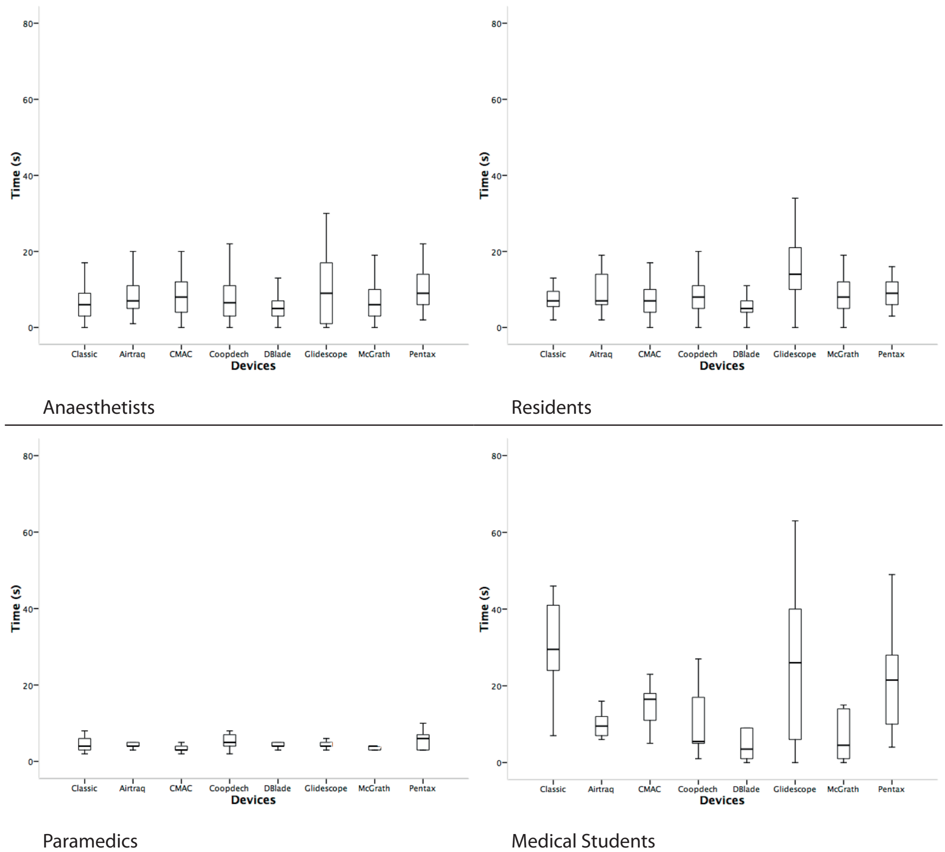
When comparing groups, paramedics achieved the best view of the glottis faster than all other groups for the C-MAC videolaryngoscope (4 (4–7 [2–22]) s; $p < 0.001$ vs. other groups) and classic Macintosh laryngoscope (5 (5–7 [2–18]) s; $p < 0.036$ vs. other groups).

Times until successful tracheal intubation was achieved are graphically displayed in Table 3. Time to successful tracheal intubation was achieved fastest with the classic Macintosh laryngoscope by anaesthetists (12 (14–21 [5–84]) s; residents (13 (13–17 [5– 58]) s and paramedics (11 (11–16 [4–45]) s; $p < 0.001$ vs. other devices). Medical students achieved successful tracheal intubation fastest when using the Coopdech videolaryngoscope (28 (26–37 [6–95]) s; however, this did not reach statistical significance ($p = 0.061$)).

When comparing groups, medical students were slower compared with all other groups with the classic Macintosh laryngoscope (38 (38–57 [9–159]) s; $p < 0.001$ vs. other groups), Airtraq (32 (28–48 [5– 175]) s; $p < 0.023$ vs. other groups), C-MAC (35 (34–45 [7–96]) s; $p < 0.019$ vs. other groups), and GlideScope (45 (45–62 [13–169]) s; $p < 0.047$ vs. other groups). For both the C-MAC (10 (10–19 [4–96]) s) and the Coopdech (14 (14–20 [6–53]) s), paramedics were the fastest of all groups ($p < 0.002$ vs. other groups).

Tracheal intubation success rates and variables are displayed in Table 4. Anaesthetists, residents and paramedics (all $p < 0.001$) were significantly less successful when using the Airtraq videolaryngoscope. Anaesthetists ($p = 0.04$) and paramedics ($p = 0.003$) also performed significantly worse when using the McGrath. Medical students were most successful when using the C-MAC, Coopdech and C-MAC D-Blade.

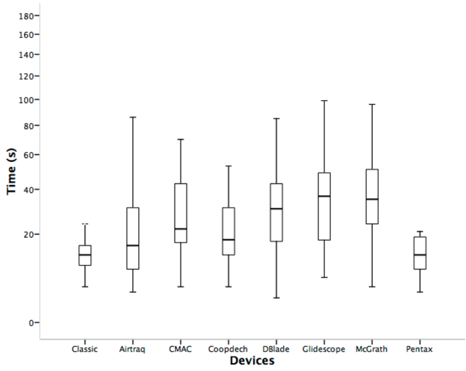
**Table 2:** Box plot representing the time until the best view of the glottis.
Bars show IQR including median, whiskers are defined as 1.5 times the IQR. Bottom whiskers represent lower limits within 1.5 times IQR, top whiskers represent upper limits within 1.5 times IQR but are not equal to maximal values, due to the removal of extreme values.



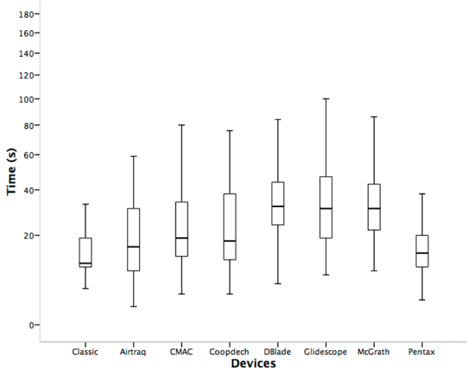

All groups needed significantly more attempts when using the Airtraq and Pentax AWS VLS (all $p < 0.047$). Paramedics needed significantly more attempts than residents when using the Airtraq videolaryngoscope ($p = 0.006$). They also needed more attempts than medical students when using the McGrath ($p < 0.001$) and Pentax AWS ($p = 0.026$).

All participants, except medical students, needed significantly more optimisation manoeuvres when using the McGrath videolaryngoscope (all $p < 0.010$).

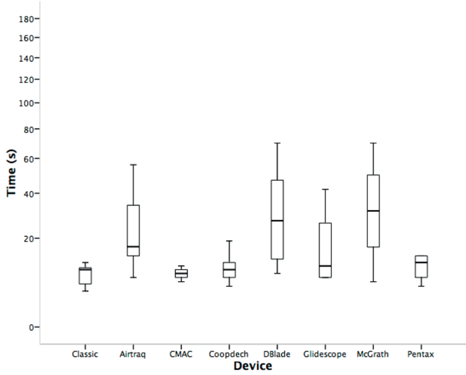
**Table 3:** Box plot representing the time until successful tracheal intubation. Bars show IQR including median, whiskers are defined as 1.5 times the IQR. Bottom whiskers represent lower limits within 1.5 times IQR, top whiskers represent upper limits within 1.5 times IQR but are not equal to maximal values, due to the removal of extreme values.



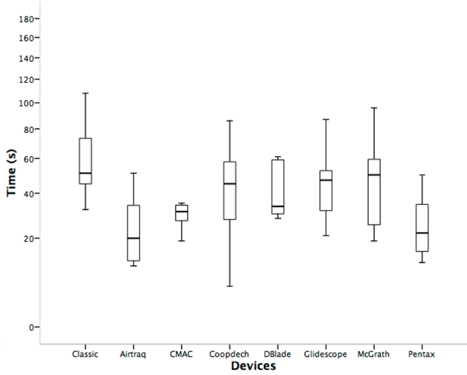

Anaesthetists




Residents




Paramedics




Medical Students

Residents and paramedics also needed significantly more optimisation manoeuvres when using the GlideScope (all $p < 0.008$) and D-Blade (all $p < 0.026$) VLS.

The C&L grade was scored significantly worse by all participants when they used the GlideScope videolaryngoscope (all $p < 0.001$). Anaesthetists (all $p < 0.014$), residents (all $p < 0.006$) and medical students (all $p < 0.001$) also got a worse view of the glottis using the classic Macintosh laryngoscope. Comparing groups, anaesthetists and paramedics scored the C&L grade lower than medical students when respectively using the classic Macintosh laryngoscope ($p = 0.030$) and Airtraq videolaryngoscope ($p < 0.001$).

All participants, except paramedics, caused significantly more audible dental clicks when using the GlideScope videolaryngoscope (all $p < 0.029$). Of these participants, 19

(29%) anaesthetists, 11 (17%) residents and 39 (70%) medical students caused audible dental clicks. Audible dental clicks were also caused by anaesthetists ($p < 0.041$) and medical students ($p < 0.038$) significantly more when using the Coopdech videolaryngoscope. Paramedics (n = 9, 17%) caused significantly more audible dental clicks when using the McGrath videolaryngoscope ($p < 0.034$). Comparing groups, paramedics caused less audible dental clicks compared with anaesthetists when using the classic Macintosh laryngoscope ($p < 0.001$); however, they caused more audible dental clicks than residents when using the Airtraq videolaryngoscope ($p < 0.001$). Medical students caused more audible dental clicks when using the Pentax AWS than anaesthetists ($p < 0.001$) and paramedics ($p = 0.005$).

Regarding preference of devices, 22 anaesthetists (34%) and 15 residents (22%) rated the classic Macintosh laryngoscope highest. Paramedics and medical students most often rated the C-MAC highest (21 paramedics (38%) and 18 medical students (28%)). The Airtraq was rated lowest most often by anaesthetists (n = 26; 40%), paramedics (n = 23; 41%) and medical students (n = 28; 43%). Residents most often rated the McGrath videolaryngoscope lowest (n = 15; 22%).

**Table 4:** Tracheal intubation succes rates and variables. Values are numbers (percentage).

| Device | Anaesthetists | Residents | Medical Students | Paramedics |
|---|---|---|---|---|
| | n = 65 | n = 67 | n = 65 | n= 56 |
| **Classic Macintosh** | 65 (100) | 67 (100) | 51 (78.5)† | 56(100) |
| **Airtraq** | 54 (83.1)* | 55 (82.1)* | 45 (69.2)† | 44 (78.6)* |
| **C-MAC** | 65 (100) | 67 (100) | 65 (100) | 50 (100) |
| **Coopdech** | 65 (100) | 55 (100) | 52 (98.1) | 52 (100) |
| **C-MAC D-Blade** | 51 (98.1) | 46 (97.7) | 31 (100) | 15 (100) |
| **GlideScope** | 63 (96.9) | 63 (94) | 58 (89.2)† | 55 (98.2) |
| **McGrath** | 59 (90.8)** | 60 (95.2) | 48 (87.3)† | 44 (84.6)*** |
| **Pentax AWS** | 63 (96.9) | 63 (94) | 59 (90.8)† | 56 (100) |

** (P < 0.01), **(P < 0.05), *** (P < 0.001) compared with Classic Macintosh*
*† (P < 0.01), (P < 0.05) and (P < 0.001) compared with C-MAC*

## DISCUSSION

Our main observation is that, for the very wide range of devices we tested, across all key groups, there was not one single device that was best for all caregivers.

For anaesthetists, residents and paramedics, the time to successful tracheal intubation was shortest when using the classic Macintosh laryngoscope. Previous experience with this device in day-to-day practice should therefore be highly valued. The learning curve for VLS may be relevant.[7] A longer time to tracheal intubation when using the

GlideScope and McGrath VLS has been reported in the literature in both manikins and patients.[8,14-17] The potential advantages of this new technology may be outweighed by the lack of familiarity with the new technique.

When using the classic Macintosh laryngoscope, the laryngeal, pharyngeal and oral axes have to be aligned to achieve the best possible view of the glottis.[18] The passage of the TT through the upper airway is then usually easily done. This could explain why participants experienced with the classic Macintosh laryngoscope were significantly slower when using the acutely angled VLS (C-MAC D-Blade, GlideScope and McGrath). Participants experienced with direct tracheal intubation may be subconsciously convinced that the axes should always be in one line when intubating.



A balance between the advantages of VLS and the disadvantage of new skill requirements can be found in VLS with a classic-shaped Macintosh blade (e.g. C-MAC and Coopdech VLS). Ideally, one is able to choose between direct and indirect laryngoscopy while in the middle of the act of tracheal intubation, changing the technique dependent on the (oral-laryngeal) situation encountered. Being familiar with the technique of DL should not be a handicap, as bringing the axes into line is not perceived to hamper the effectiveness of the videolaryngoscope.[14]

It may be argued that the difference of a few seconds is not clinically relevant. However, those few extra seconds taken to try and manipulate the TT once more may result in oedema, cause more trauma and make future attempts more difficult. More attempts are likely to result in even more trauma. The concept of 'time is brain', should not be underestimated as in our view 'every second counts'.

Medical students needed significantly more attempts when using the classic Macintosh laryngoscope. This reflects the results shown in previous studies; an average of 57 attempts is needed to achieve a 90% success rate of intubation with DL.[19]

Medical students produced significantly more audible clicks when using the classic Macintosh laryngoscope compared with the Airtraq, C-MAC, D-Blade, McGrath and Pentax AWS VLS. Being of a generation used to playing video-games, they may have better indirect eye-hand coordination than some experienced participants of an older generation.[20] They are, however, not used to the technique of DL and are more likely to use the maxillary incisors as a fulcrum. Although the C-MAC videolaryngoscope also has a classic Macintosh blade, our results for the C-MAC are consistent with our previous findings that, even for experienced anaesthetists, the use of the C-MAC results in less pressure applied to the maxillary incisors.[21-23]

Our study has several limitations, notably that it is a manikin study. Findings are not directly transferable to acute clinical care, but manikins can provide reliable, standardised comparative evaluation of new equipment or techniques.[24,25] Due to the large numbers of participants and devices, we wanted to ensure standardised, consistent, true laryngoscopy each time to allow adequate device comparison. Ethically, it is preferable to limit patient risk, especially with so many inexperienced participants: we were able to include 56 paramedics (86%) because they work in small units and are en-route a lot during a shift. Paramedics may have performed better than expected because they were more familiar with regular manikin training. This does not invalidate the present study as there was a positive result, but it may mean that some comparisons that were not significant might in fact have been significant with a larger sample size.

We note that not all the devices we studied are always readily available elsewhere. The decision to use a stylet was left to the intubator, whereas manufacturers of GlideScope and McGrath VLS advocate routine use. The absence of an external monitor may influence the users' preference (e.g. the Airtraq does not have a video screen). Our study was not blinded, which could have led to altered performance as a result of the Hawthorne effect (individuals improve or modify their behaviour because of their awareness of being observed).[26] We appreciate that the C&L grade has been described for DL, not videolaryngoscopy. The percentage of glottic opening may be better for documentation of videolaryngoscopy, but we do not think our results would greatly differ if an alternative scale had been applied.[25]

In conclusion, while there are major differences between tracheal intubation in manikins and in patients, we believe this trial contributes to the understanding as to how VLS vary in their ability to facilitate tracheal intubation for different caregivers.

The choice of a laryngoscope should be made based on requirements of the device and the person using it. This has implications for hospital providers. While they might sensibly take advice from their core staff as to the choice of main device to purchase (ideally, in turn, based on published evidence[27]), they should also rationally stock a range of devices to account for differences in performance across individuals and staff groups, as we have demonstrated. Failing to acknowledge this reality might compromise patient safety.

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# Chapter 5

## Videolaryngoscopes differ substantially in illumination of the oral cavity: a manikin study

Pieters BM, van Zundert AA.

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## ABSTRACT

Background and Aims: Insufficient illumination of the oral cavity during tracheal intubation may result in suboptimal conditions. Consequently, suboptimal illumination and laryngoscopy may lead to potential unwanted trauma to soft tissues of the pharyngeal mucosa. We investigated illumination of the oral cavity by different videolaryngoscopes in a manikin model.

Methods: We measured light intensity from the mouth opening of an intubation trainer manikin comparing different direct and indirect videolaryngoscopes at three occasions, resembling optimal to less-than-optimal intubation conditions; at the photographer's dark room, in an operating theatre and outdoors in bright sunlight.

Results: Substantial differences in luminance were detected between videolaryngoscopes. The use of LED light significantly improved light production. All videolaryngoscopes produced substantial higher luminance values in a well-luminated environment compared to the photographer's dark room. The experiments outside - in bright sunlight - were interfered by direct sunlight penetration through the synthetic material of the manikin, making correct measurement of luminance in the oropharynx invalid.

Conclusion: Illumination of the oral cavity differs widely among direct and indirect videolaryngoscopes. The clinician should be aware of the possibility of suboptimal illumination of the oral cavity and the potential risk this poses for the patient.

## INTRODUCTION

Indirect videolaryngoscopes (VLS) make tracheal intubation possible without extensive experience.[1-3] Since their introduction,[4] the singular goal is optimal visibility of the pharyngolarynx.

An underestimated aspect of the design is lighting. When illumination is poor, positioning the tracheal tube (TT) is difficult, potentially traumatizing soft tissue, especially when using a rigid stylet.[5]

The aim of this study was to compare the intensity of illumination from the light source between different VLS. Devices were compared in a photographer's dark room, an operating theatre and outside in bright sunlight. The intensity of light was measured at the oral cavity opening of an Airway Trainer™ manikin (Laerdal Stavanger, Norway) intubation trainer.



## METHODS

We informed and consulted the Institutional Review Board concerning this study. The Board decided that formal review was not necessary as this study did not involve any patients nor participants other than the investigators.

In this in vitro study, using a manikin, fourteen different VLS were compared, readily available at the institution where both authors were employed at the time of the study (respectively as resident and professor in anaesthesia): Coopdech VLP-100® (Daiken Medical, Tokyo, Japan), C-MAC® (8402 ZX Monitor) and C-MAC PM® (Karl Storz, Tuttlingen, Germany), GlideScope Ranger® (Ranger Single Use System) and GlideScope Cobalt® (GVL System) (Verathon Medical, Bothell, WA, USA), King Vision channelled® and MAC® (King Systems, Noblesville, IN, USA), McGrath Series 5® and MAC EDL® (Aircraft Medical, Edinburgh, UK), Venner AP Advance channelled® and MAC® (Venner Medical, Kiel, Germany), Airtraq A-011® (Prodol, Vizcaya, Spain), Pentax AWS-S100® (Pentax Corporation, Tokyo, Japan) and a classic direct laryngoscope (Brite Blade® LED) (Karl Storz, Tuttlingen, Germany).

Measurements were performed at three different locations; the photographers' dark room, the operating theatre and outside, in bright sunlight (copying tracheal intubation in a prehospital setting).

The investigator placed the videolaryngoscope in the manikin's mouth, achieving the best possible view of the glottis. Once achieved, width and depth of vision were analysed by scoring the Cormack and Lehane (C&L) grade. The C&L grade was scored to make the quality of laryngoscopy as uniformly as possible, it was not used as a way to score oral illumination.

Hereafter, a professional photographer, knowledgeable in measuring light intensity, measured light intensity from the opening of the oral cavity, using a Sekonic L-758Cine Digital

Master® light meter (Sekonic Corporation Japan, Tokyo, Japan), set to cd/m$^2$. The light meter was placed inside the oral cavity. Due to the size of the light meter, this was within 2 cm of the mandibular dental margin. All VLS had fully loaded new batteries inserted, or were used while directly connected to mains electricity. Light intensity was measured three times per videolaryngoscope and defined as luminance (cd/m$^2$), the amount of light emitted or re-emitted per unit area of a surface in a given direction.[6,7] At the operating theatre, all ceiling lamps were lit along with one satellite lamp. This satellite lamp (KLS Martin, Tuttlingen, Germany; VAC 50/60 Hz, 24 VDC, 300 VA) was directed towards the thorax of the same Laerdal manikin, resembling normal tracheal intubation conditions.

After the experiment, we analysed the illumination by the different VLS by comparing the values of luminance (cd/m$^2$).

## RESULTS

A C&L grade I was achieved with every laryngoscopy. As depicted in Tables 1 and 2, the measurements of luminance differed substantially among devices. In the photographer's dark room, luminance ranged from 1.2 cd/m$^2$ (Pentax AWS) to 73.2 cd/m$^2$ (C-MAC).

**Table 1:** Light intensity (luminance cd/m2) per non-channelled (video) laryngoscope (Macintosh design blade)

| Device (video) laryngoscope | Power supply | Luminance cd/m2 | |
|---|---|---|---|
| | | Photographer's dark room | Operation theatre |
| Direct Macintosh | 2.5 VNiMH battery | 15.0 | 50.0 |
| McGrath Series 5 | Single AA (Mignon/IEC-LR6 battery) 1.5 V battery | 3.7 | 2.7 |
| McGrath MAC | Proprietary 3.6 V Lithium Battery Pack | 4.3 | 4.3 |
| GlideScope Cobalt | 7.2 V 2200 mAh Li-ion battery | 2.6 | 5.7 |
| King Vision MAC | Three AA (Mignon/IEC-LR6 battery) 1.5 V batteries | 3.4 | 15.0 |
| Coopdech | 3.7 V DC 1500 mAh Li-ion battery - rechargeable | 2.3 | 17.3 |
| Venner MAC | Handle: AA (Mignon/IEC-LR6 battery) 1.5 V Battery Monitor: rechargeable batteries | 24.6 | 25.3 |
| GlideScope Ranger | 12 V DC battery - rechargeable | 1.6 | 30.0 |
| C-MAC PM | 12 V DC battery - rechargeable | 30.0 | 64.0 |
| C-MAC | 12 V DC battery - rechargeable | 73.2 | 110.0 |

*Data are presented as mean*

**Table 2:** Light intensity (luminance cd/m2) per channelled videolaryngoscope

| Device channelled (video) laryngoscope | Power supply | Luminance cd/m2 | |
|---|---|---|---|
| | | Photographer's dark room | Operation theatre |
| Pentax Airway Scope | Two AA (Mignon/IEC-LR6 battery) 3 V batteries | 1.2 | 8.0 |
| Airtraq | Single use (60 min battery life expectancy) | 3.3 | 10.0 |
| King Vision | Three AA (Mignon/IEC-LR6 battery) 1.5 V batteries | 5.0 | 12.0 |
| Venner | Handle: AA (Mignon/IEC-LR6 battery) 1.5 V battery<br>Monitor: Rechargeable batteries | 50.6 | 80.0 |

*Data are presented as mean*



In the operating theatre, large differences in luminance were measured among the VLS, ranging from 2.7 cd/m$^2$ (McGrath series 5) to 110.0 cd/m$^2$ (C-MAC). All VLS, except McGrath series 5 and McGrath MAC, produced substantial higher luminance values in a well-illuminated environment compared to the dark photographer's room (Figures 1 and 2).

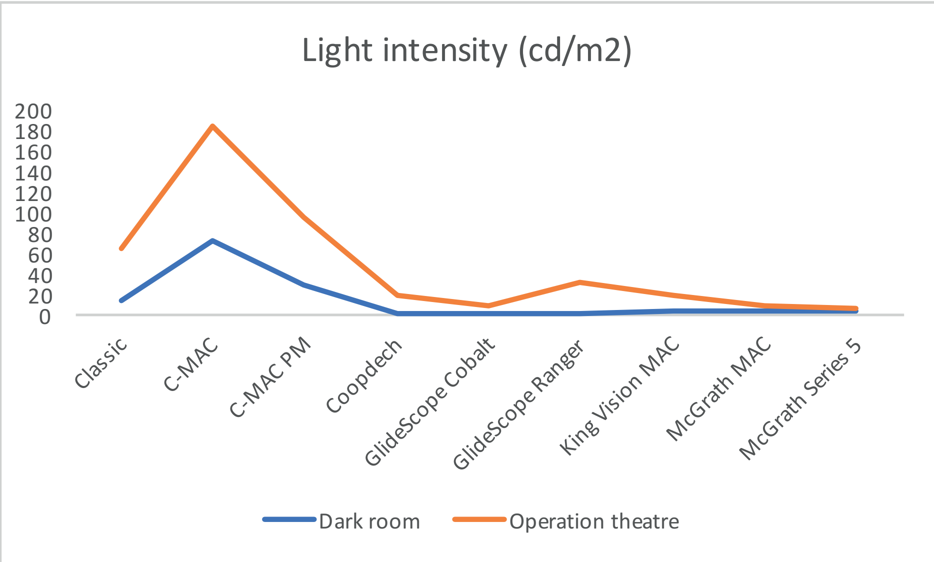


**Figure 5.1:** Light intensity measured in non-channelled (video) laryngoscopes

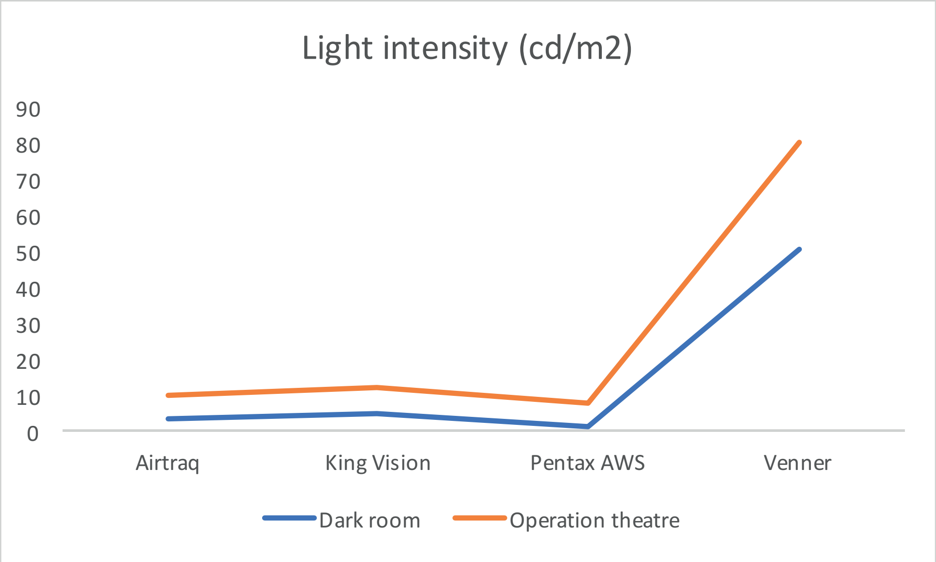


**Figure 5.2:** Light intensity measured in channelled (video) laryngoscopes

Our experiments in bright sunlight were interfered by direct sunlight penetrating through the synthetic material of the manikin. This caused the light meter to measure the intensity of sunlight instead of light intensity of the laryngoscopes. This was the case for both the VLS and the direct laryngoscope.

## DISCUSSION

The existing VLS mainly differ whether they use: (1) channelled or non-channelled blades; (2) classic Macintosh curved, or more acutely angled blades; and (3) whether the illumination results from halogen, xenon bulbs or LED light origin.

All of the above have major implications for the anaesthetist. A clear visibility of the oropharynx and laryngeal entrance and the availability of substantial space in the mouth for manoeuvring a TT and other adjuncts (e.g., gum elastic bougie, stylets, oro/nasogastric tube, Magill forceps) are keys to success. Videolaryngoscopy has proven to result in successful tracheal intubation more easily.[8,9] So although less than optimal illumination does not have to result in unsuccessful tracheal intubation, the risk of trauma remains. Indeed, it is important that we clearly see what we do during any manipulation in the mouth to avoid trauma. The existence of so-called 'blind spots' is known to cause palatal, palatopharyngeal and tonsillar trauma.[5,10,11] For DL, the minimum required luminance is reported to be 100 cd/m$^2$ at the centre of the light field. The optimum dimensions of the light field hereby were however not reported.[7] To the best of our knowledge, such information is not available for VLS. The minimum required luminance for VLS is not yet known. Although we cannot determine the minimum required amount of illumination to prevent oral trauma, when the amount of illumination is 40 times less than the minimum required for DL, the caregiver should be well aware of this.

Over the years, illumination of the oral cavity during DL was improved significantly by changing the filament bulbs, and later by changing the halogen or xenon bulbs into the more solid-state LED lights. Compared to conventional bulb-on-blade laryngoscope lighting systems (using halogen light), LED bulbs use very little energy, operate with less heat, produce a brilliant light and have a much longer lifespan than the earlier bulbs (15,000–30,000 hours compared to approximately 1000 hours), thereby eliminating the need for bulb replacement. Improvement in quality and longevity of batteries and using the mains, further improved illumination options and visibility for both direct and video laryngoscopes.



One can argue if the reported minimum required luminance of 100 cd/m$^2$ for DL also holds true for VLS. Indeed, the techniques are not simply interchangeable. On the other hand, the importance of seeing what one is doing while passing a TT (especially one with a rigid stylet in situ!) is applicable to both techniques. When applying this limit of 100 cd/m$^2$ to this study, illumination in all tested VLS (except the C-MAC) is poor when used in the operating theatre.

Our finding, that due to extensive glare on the monitor screen of different VLS tracheal intubation in bright sunlight while looking at the screen is severely hampered, needs further investigation. The material of the manikin is penetrated by direct sunlight, in contrast to human skin. As a consequence, we cannot draw conclusions from this part of our study, but we can conclude that studies in bright sunlight involving manikins have severe limitations.

Prehospital tracheal intubation has highly variable success rates and can be challenging due to patient immobilisation, entrapment, air medical evacuation, constrained access to the patient, poor patient positioning and variable ambient lighting. VLS have been used in the field where sunlight is very intense.[12,13] Our finding (hampered tracheal intubation due to extensive glare) could, however, have major implications for the caregiver in the prehospital setting (e.g., ambulance, air-ambulance services and war zone circumstances) and should be taken into account when choosing a device.

Videolaryngoscopy, using channelled VLS, may impair direct visibility of the oral cavity by the significant additional volume of the blade itself or the acute angle of the blade, whereby the light produced at the top illuminates more the anterior part of the laryngeal entrance, and not necessarily the whole mouth. This is in contrast with VLS that use a Macintosh design blade whereby a larger part of the oral cavity is illuminated. We believe that the triad: (1) less room to manoeuvre in the mouth; (2) distraction by 'looking at the monitor screen' outside the mouth: and (3) the use of a sharp, rigid styletted

TT combined with less optimal illumination possibly resulting in 'blind spots', may pose a greater risk to harm the patient (oesophageal intubation and trauma).[5,10,11]

There are limitations to this study. First, it is a manikin based study. The goal of the study was to compare the intensity of illumination between different VLS. To compare different devices in exactly the same circumstances, it would have been necessary to place all the different VLS in the same persons' mouth. Ethically this is not correct, and for a first comparison not even necessary. Light intensity in humans may be different due to absorption and/or reflection by the manikin. Comparing maybe one or two different devices could perhaps be done in a group of patients/volunteers. Another solution may be a cadavre study.

Second, background light (in the operating theatre) could possibly have influenced the measurements more than the light emission per se. However, we performed a baseline recording when we compared illumination by the different devices in a photographer's dark room. This way, we got a primary idea on the amount of light emitted by the VLS, and when using a videolaryngoscope, virtually there always is background light.

When comparing illumination, we chose to place the light meter at the opening of the oral cavity. This is the same position the eye of the caregiver (thus the 'light meter' of the caregiver) normally has. The eye of the operator registers the amount of light from the opening of the oral cavity when manoeuvring the TT before looking at the video screen. As stated by Vincent and colleagues 'it is important to advance the TT beyond the uvula before directing one's attention to the video monitor'.[14] Precisely the fact that the amount of light emitted and the amount of light reaching the eye of the caregiver may significantly differ could pose an extra risk to the patient. When the image on the screen is well lit, but there is little light reaching the eye when one is looking into the oral cavity and not looking at the video screen, one is still poking in the dark, which poses a subsequent risk to the patient! Even when the amount of light emitted is enough to (easily) intubate a patient (although maybe not the preferred 100 cd/m$^2$), suboptimal illumination poses a risk to the patient, especially that of palatopharyngeal trauma.

We wanted to investigate the relationship between light emission by VLS and oral cavity illumination. Measuring light emission at the laryngeal entrance would provide a different parameter. The relationship between light emission at the oral cavity and light emission at the laryngeal entrance is not well described in current literature. Furthermore, a search for suitable equipment small enough to measure light emission from the laryngeal entrance learned that it is not available.

Third, the synthetic material of the manikin may not only be penetrated by direct sunlight but possibly also by the light of the lamps in the operating theatre. When this is true, the amount of penetration would have been the same for all devices for all measurements and thus does not influence the comparison between devices. The fact that in the operating theatre for the McGrath series 5 and McGrath MAC the amount of light measured is less (McGrath series 5) and the same (McGrath MAC) as in the photographer's dark room, contradicts penetration of the synthetic material of the manikin. It is also possible that the material of the manikin reflected the light of the devices. When this is true, this may result in a different level of illumination when the VLS are used in humans, but again this is valid for all devices, which makes comparison still possible.

Fourth, we did not investigate if there are differences when a device is connected to mains instead of working on a (fully charged) battery. Possibly, the light output is better when a videolaryngoscope is connected to mains.

Finally, we used a LED lit direct laryngoscope (Karl Storz, Tuttlingen, Germany), as which was the standard in hospital use for tracheal intubation. It would have been interesting to know how a direct laryngoscope using a conventional light bulb would perform, compared to different VLS.



## CONCLUSION

Illumination of the oral cavity differs substantially among VLS in a manikin model. Illumination is best when using the C-MAC videolaryngoscope. Comparing these results with the recommendations made previously for DL, illumination is poor with all VLS tested, except for the C-MAC when used in the operating theatre. Clinicians should be aware of these shortcomings and differences between devices.

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# Chapter 6

## Indirect videolaryngoscopy using Macintosh blades in patients with non-anticipated difficult airways results in significantly lower forces exerted on teeth relative to classic direct laryngoscopy; a randomized crossover trial

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Minerva Anestesiol. 2015; 81: 846-54.

## ABSTRACT

Background: Videolaryngoscopy has proven advantageous over direct laryngoscopy for a variety of outcome variables, most importantly, making laryngoscopy more successful.

We tested whether three videolaryngoscopes, McGrath series 5®, C-MAC® and GlideScope Cobalt® exert reduced forces on maxillary incisors and lower teeth, and compared them with a classic Macintosh MAC 3 blade laryngoscope during laryngoscopy.

Methods: In this randomized cross-over trial, we included 141 patients (ASA I-III) with non-anticipated difficult airways. They were randomly allocated to undergo direct laryngoscopy and videolaryngoscopy performed with one of three videolaryngoscopes.

Primary outcome was the magnitude of forces applied to the maxillary incisors during laryngoscopy. Secondary outcomes were the frequency with which forces were applied, and the magnitude of forces applied to the lower teeth.

Results: Forces applied to the maxillary incisors during direct classic laryngoscopy were on average higher than forces applied during videolaryngoscopy. Among the videolaryngoscopes the average force applied was significantly lower for the C-MAC as compared to the McGrath and the GlideScope. The frequency with which a force was applied to the maxillary incisors was significantly lower for the C-MAC, compared to the other videolaryngoscopes and classic Macintosh laryngoscope. The number of cases in which force was applied to the lower teeth was smallest for the McGrath videolaryngoscope.

Conclusions: Forces exerted on maxillary incisors are lower using video-assisted Macintosh blade laryngoscopy compared to classic direct laryngoscopy. The number and magnitude of forces applied to maxillary incisors also differ substantially between different videolaryngoscopes.

## INTRODUCTION

During tracheal intubation, the anaesthetist has to avoid using the maxillary incisors as a fulcrum to lever the soft tissues upwards. This may otherwise result in dental trauma. It is obvious that contact with teeth and – even worse – the incidence of accidental dental trauma, are directly related to the difficulty of the intubation.[1]

Videolaryngoscopy has proven advantageous over direct laryngoscopy (DL) using a classic Macintosh blade, for improved viewing of the glottis, with subsequent more successful intubations, and a shorter effective airway time both in patients with non-anticipated difficult and anticipated difficult airways.[2,3] Previously, it has been demonstrated that the forces applied to the patient's maxillary incisors are reduced when using a videolaryngoscope, compared to a classic Macintosh laryngoscope. However, in these studies only one type of videolaryngoscope (V-MAC® (Karl Storz, Tuttlingen, Germany) or Airtraq® (Prodol, Vizcaya, Spain)) was used.[4,5] In the other, different types of videolaryngoscopes (VLS) than the ones used in this study were investigated, and forces on lower teeth were not investigated.[6]



We tested whether three different brands of VLS, i.e. McGrath series 5® (Aircraft Medical Ltd, Edinburgh, UK), C-MAC® (Karl Storz, Tuttlingen, Germany) and GlideScope Cobalt® (Verathon Medical, Bothell, WA, USA) apply similar reduced forces on both maxillary incisors and lower teeth, and compared them with a classic Macintosh MAC 3 blade laryngoscope.

The primary outcome was the magnitude of forces applied to the maxillary incisors.

Secondary outcomes were the frequency with which forces were applied and the magnitude of the forces applied to the lower teeth.

## MATERIALS AND METHODS

After obtaining Institutional Review Board approval (Catharina Hospital Eindhoven, The Netherlands (Chairman: dr. R. Grouls), registration M12-1217), CCMO registration (NL39915.06012) and registration at Clinical Trials (NCT01599312), written informed patient consent was obtained. In total, 150 consecutive patients (ASA I-III) with non-anticipated difficult airways, undergoing a variety of surgical interventions, for which tracheal intubation was indicated, were enrolled in this randomized crossover trial between May and September 2012 at the Catharina Hospital Eindhoven. The patients were randomly allocated, using computer-generated tables, to receive DL (classic Macintosh laryngoscope (MAC 3 blade)) and one of three VLS: McGrath, C-MAC or GlideScope. The C-MAC was used with indirect (monitor) viewing throughout the experiment. Exclusion criteria were no informed patient consent, patients younger than 18 years, patients requiring other than size 3 blade Macintosh laryngoscope, patients with preoperative predictors of a difficult airway (Mallampati score IV, restricted neck movement, thyromental distance < 65 mm, interincisor/interdental distance < 35 mm), patients with ASA class ≥ IV, emergency surgery, surgery of head and/or throat, locoregional anaesthesia, patients fasted < 6 hours, bad dentition, dental crowns and/or fixed partial denture. Patients were enrolled during the preanaesthetic visit of the patient (performed by anaesthetists not involved in this study). During this visit, patient characteristics mentioned above (with respect to exclusion criteria) were recorded.

When the patients arrived in the OR, they were connected to standard monitoring devices. Patients were placed in the supine position with the patient's head resting on a pillow 8 cm in height. After three minutes of oxygen administration, IV induction of anaesthesia was performed with 1 μg/kg fentanyl, 3 mg/kg propofol, and rocuronium 0.7 mg/kg, followed by manual ventilation via a facemask using sevoflurane in oxygen. The laryngoscope was inserted at least 90 seconds (s) after completion of induction, and only when the anaesthetist considered the level of anaesthesia adequate for intubation and the end-tidal sevoflurane concentration was ≥1.5%. Muscle paralysis was measured using the train-of-four-ratio.

The patients had the classic Macintosh laryngoscope placed in their mouth. The anaesthetist subsequently determined the best possible view of the glottic opening and a tracheal tube (TT) (7.5 mm for men, 7.0 mm for women) was brought into position in front of the glottic opening. After the Macintosh laryngoscope was removed, one of three VLS was placed in their mouth and the procedure was repeated. Actual intubation was only performed with the videolaryngoscope. Three anaesthetists, familiar with the tested VLS (minimum 100 uses on actual patients) and classical intubation, participated in the study. They were specifically instructed in avoiding any contact with the teeth. We chose to instruct anaesthetists in this way because we could not blind them for the sensors placed on the laryngoscope blade. The participating anaesthetists did know the purpose of the study and therefore may have taken extra care in avoiding dental trauma.

Effective airway time was measured as the time between picking up the TT and placing it in front of the glottic opening (in case of the classic Macintosh laryngoscope) or insertion between the vocal cords (in case of the videolaryngoscope). Each approach towards the glottic opening was counted as an intubation attempt. After two unsuccessful attempts a stylet was inserted into the TT to facilitate intubation. Patient characteristics (i.e. weight, age, gender, height, BMI), specific metrics of intubation difficulty (i.e. Mallampati grade, thyromental distance, neck movement, mouth opening, dentition, Cormack and Lehane (C&L) grade, number of intubation attempts), and any complication were recorded.

The method used to measure the forces applied to the teeth (dependent parameter) for the duration of insertion of each laryngoscope was the same as used by Lee et al., using Flexiforce® sensors (A201-25, Tekscan, MA, USA). These were fixed to the blade of the laryngoscope at the possible area of contact with the teeth. Three sensors were mounted on top of the blade (the site of the blade directed at the maxillary incisors during intubation) along its length and three at the bottom of the blade (the site of the blade directed towards the tongue during intubation) (Figure 1).[4,6] This configuration completely covers the possible contact points between the blade and the teeth. The sensors are rated to 110 N. Calibration was performed by applying a known mass (from 1 to 12 kg, in steps of 1 kg) using a flat-headed screwdriver (as geometrical approximation of the contact with the teeth) to the sensors mounted upon the blade. The sensors were invariant to the contact point of the applied load. Each of the sensors was individually calibrated in situ. The sensors were cleaned and sterilized between each use by submersion of the blade in chlorhexidine 0,5% in alcohol 70%. The sensors were assumed to work reliably, as the forces were an order of magnitude lower than required to permanently damage the sensor. This assumption was tested by calibration tests at the end of the experiments, whereby none of the sensors indicated degradation.



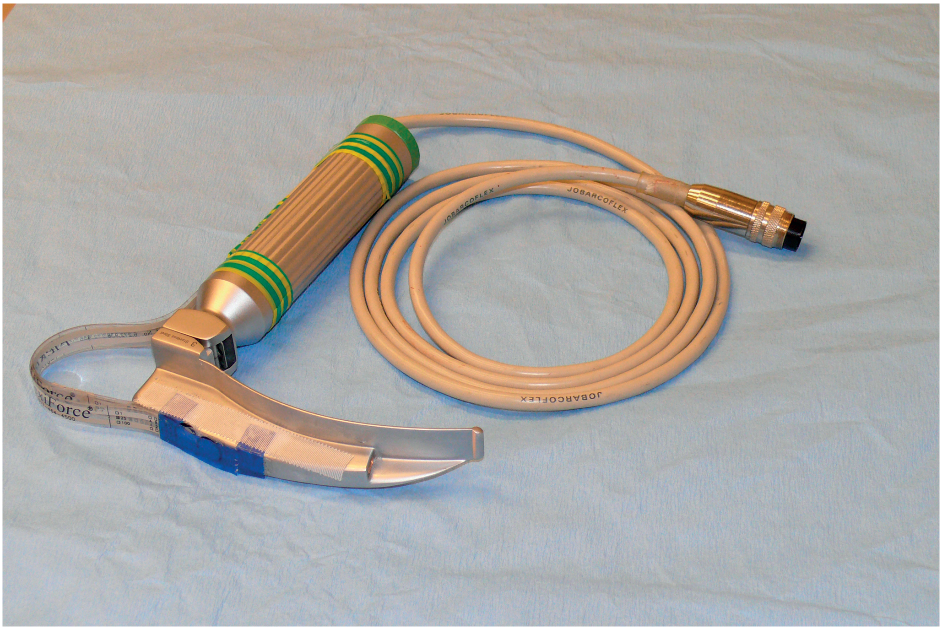


**Figure 6.1:** Flexiforce® sensors (A201-25, Tekscan, MA, USA) fixed to the blade of the laryngoscope.

Data acquisition was achieved with a National Instruments® (DAQ6009 (National Instruments Corporation, TX, USA) card at 500 Hz, using Labview® 7.0 (National Instruments Corporation, TX, USA) on a laptop computer (Hewlett Packard Company, CA). Peak forces were subsequently noted for each of the patients. Because drift and noise in the sensors could result in very low but incorrectly detected contact forces between the teeth and the blade we used a threshold of 2N to determine whether a force was applied to the teeth or not. All registrations of forces applied to the maxillary incisors or lower teeth were registered on the laptop computer in such a way that these were completely blinded for the anaesthetist who intubated the patient's trachea. The results of these measurements were only available to an engineer (JVD) of the Technical University Delft, The Netherlands.

Prior to the experiment we performed a power analysis to estimate the required sample size of patients required for finding differences between the magnitudes of used forces. We were interested in finding a difference between the laryngoscopes of at least 20N as, based on earlier results by Lee et al., we assumed that such a difference would have a significant clinical value.[4,6] Furthermore, we used a standard deviation of 20N as an estimate of the population variability, the latter being based on the variability found in our previous study.[4] Using these assumptions, the power analysis showed that an appropriate sample size to achieve adequate power was at least 22 measurements per laryngoscope. The actual sample size used in the experiment was twice as large for each of the VLS to overcome possible exclusions for technical failure, while each insertion with a videolaryngoscope was also paralleled with a measurement with the classic laryngoscope. For the cases in which forces (>2N) were applied, we determined whether the magnitude of force differed among the laryngoscopes.

Non-parametric testing was used to compare medians across groups using the Median Test for k samples (IBM SPSS 19 (IBM Corporation, NY 10589, USA)). We made six comparisons between groups for each depended variable (force, lower, teeth, maxillary incisors and time). Corrections were made for multiple hypothesis tested using Bonferroni (i.e. = alpha/k=0.05/6).

## RESULTS

All 150 patients were successfully intubated in the study. However, in nine patients in the videolaryngoscopy group and in one patient in the DL group, registration of forces was not realized due to technical problems.

The actual sample size was larger than initially calculated by the power analysis, because during the study it was not directly clear how many measurements were lost due to the technical problems. Therefore, the study included the results of 141 patients (63 males and 78 females), all intubated with one of the three VLS. Patient characteristics are given in Table 1, results obtained during laryngoscopy in Table 2. No differences were seen between the groups regarding patient characteristics, the objective metrics of intubation difficulty, and C&L grade, although the latter differed significantly between direct and indirect laryngoscopy.

**Table 1:** Patient Characteristics.

| | Classic<br>N = 141 | McGrath<br>N = 48 | C-MAC<br>N = 47 | GlideScope<br>N = 46 |
|---|---|---|---|---|
| Male: female ratio, n | 63:78 | 22:26 | 21:26 | 20:26 |
| Age; years | 53.8 ± 15.5 | 55.5 ± 15.0 | 51.9 ± 15.0 | 54.2 ± 16.6 |
| Height; cm | 171.5 ± 8.9 | 172.4 ± 9.4 | 171.3 ± 9.0 | 171.0 ± 8.5 |
| Weight; kg | 81.6 ± 19.3 | 80.1 ± 15.6 | 80.4 ± 20.1 | 84.5 ± 21.9 |
| BMI; kg.m$^{-2}$ | 27.7 ± 6.3 | 27.0 ± 6.2 | 27.4 ± 7.1 | 28.9 ± 7.4 |
| ASA class I:II:III, n | 45:87:9 | 16:31:1 | 15:28:4 | 14:28:4 |
| Mallampati score I: II: III: IV, n | 70:59:12:0 | 25:20:3:0 | 21:20:6:0 | 24:19:3:0 |
| Thyromental distance; mm | 83.4 ± 10.5 | 84.3 ± 9.9 | 84.1 ± 8.4 | 82.4 ± 3.5 |
| Interincisor/interdental distance; mm | 43.4 ± 6.6 | 44.0 ± 6.4 | 43.5 ± 6.1 | 43.2 ± 7.2 |
| Denture: double: single: none, n | 104:9:28 | 34:1:13 | 36:4:7 | 34:4:8 |
| Adequate neck movement; yes/no, n | 141:0 | 48:0 | 47:0 | 46:0 |

*Values are numbers, or mean ± SD*

6

**Table 2:** Results obtained during laryngoscopy using three VLS (McGrath, C-MAC, GlideScope) and the classic Macintosh laryngoscope (blade 3).

| | Classic<br>N = 141 | McGrath<br>N = 48 | C-MAC<br>N = 47 | GlideScope<br>N = 46 | P-value |
|---|---|---|---|---|---|
| C&L grade<br>I:II:III:IV (n) | 77:52:10:2*<br>(55:37:7:1) | 47:1:0:0<br>(98:2:0:0) | 43:4:0:0<br>(91:9:0:0) | 41:5:0:0<br>(89:11:0:0) | <0.05 |
| Effective airway time, s | 22 ± 13 | 28 ± 12 | 11 ± 6* | 27 ± 12 | <0.001 |
| Intubation attempts;<br>1:2:3:4 (n) | N/A | 7:11:18:12<br>(15:23:37:25) | 36:10:1:0*<br>(77:21:2:0) | 6:12:19:9<br>(13:26:41:20) | <0.001 |
| Intubation failures | N/A | 0 | 0 | 0 | NS |
| Use of stylet; yes:no (n) | N/A | 30:18<br>(63:37) | 1:46 *<br>(2:98) | 28:18<br>(61:39) | <0.001 |

*Values are numbers (%), or mean ± SD, NS = not significant, N/A = not applicable*
** Significant difference between * and the other groups.*

Figures 2 and 3 display the peak force per laryngoscope for the maxillary incisors and lower teeth, respectively, averaged across all measurements. Figure 2 shows that the force applied with the classic laryngoscope (30.2 ± 33.9 N) was on average higher than the force applied with the VLS (16.2 ± 17.4 N, McGrath (not significant (NS)); 9.31 ± 11.3 N, GlideScope ($p<0.004$)) and that the average force applied was lowest for the C-MAC (1.18 ± 4.73 N ($p<0.001$)). Post Hoc testing revealed that the average force applied for the C-MAC videolaryngoscope is significantly lower than the average forces found for

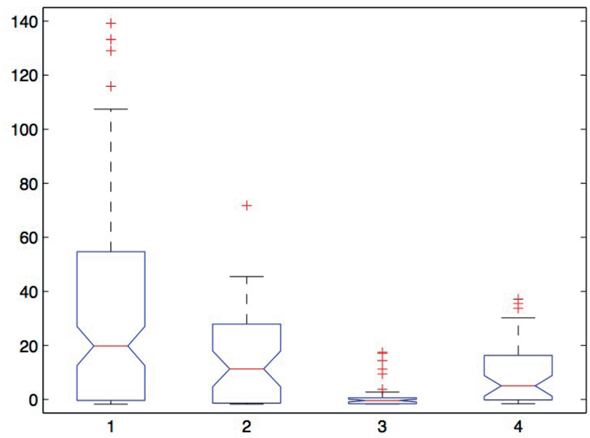


**Figure 6.2:** Peak force for the maxillary incisors per laryngoscope, averaged across all measurements.

the McGrath (p<0.001) and the GlideScope VLS (p=0.001). Table 3 displays the median and inter quartile range (IQR) for the forces applied to the maxillary incisors, across all measurements. Figure 3 proves that hardly any force was exerted on the lower teeth with any of the laryngoscopes. The differences between median forces for the classic laryngoscope (2.5N (IQR 7.5N)) and the C-MAC (2.6N (IQR 8.2N)) were very small. For the GlideScope (<0N (IQR 4.3N)) and McGrath VLS (<0N (IQR 1.1N)), median forces were negligible.

**Table 3:** Forces (Newton) applied per laryngoscope for the maxillary incisors (across all measurements).

| | **Classic N = 141** | **McGrath N = 48** | **C-MAC N = 47** | **GlideScope N = 46** | **P-Value** |
|---|---|---|---|---|---|
| Median | 17.1 | 16.5 | -0.4 | 5.0 | |
| IQR | 54.5* | 24.6 | 2.2 | 16.0 | <0.001 |

** Significant difference between * and the other groups.*

The results displayed in Figures 2 and 3 also incorporate the cases in which no contact was made between the teeth and the blade, effectively lowering the average peak force. To determine whether the applied force differs among the various laryngoscopes we selected the cases in which contact was made between the teeth and the blade, and in which force (> 2N) was applied to the maxillary incisors, before computing the averages. The results are displayed in Figure 4. Figure 4 shows that the peak force applied to the maxillary incisors with the classic laryngoscope (44.6 ± 30.8 N) was on average higher

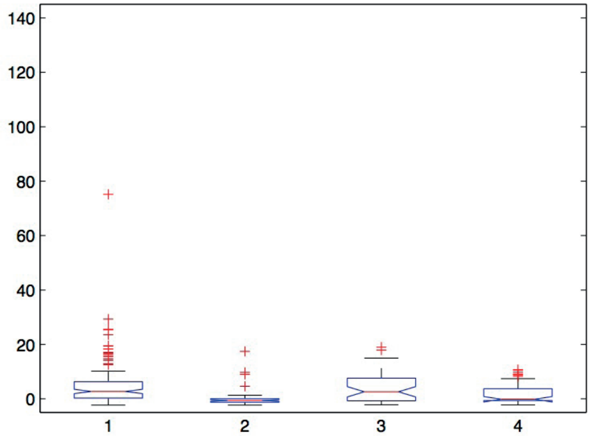


**Figure 6.3:** Peak force for the lower teeth per laryngoscope, averaged across all measurements.



than the force applied with the VLS and that the average force was lowest for the C-MAC (11.5 ± 8.1 N).

Post hoc testing revealed that there was a significant difference between the average peak force found for the classic Macintosh laryngoscope and the average values

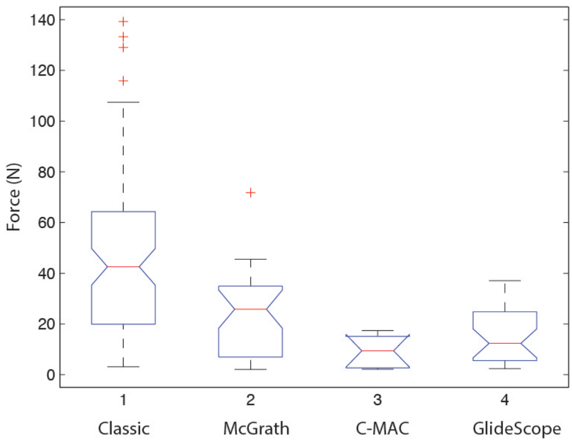


**Figure 6.4:** Average peak force for the maxillary incisors per laryngoscope. Averages are based on the selection of cases in which contact was made between teeth and blade.

found for the VLS. The difference between the C-MAC and the other VLS did, however, not reach significance. For the lower teeth (Figure 5), the peak force found for the different laryngoscopes was low, the median being 1.5 N. The mean forces applied to the lower teeth were significantly lower for the McGrath compared to the classic Macintosh laryngoscope (p<0.001). Of the other averages, none were significantly different from each other.

Tables 4 and 5 summarize the proportion of cases where contact was made with the upper and lower teeth, respectively.

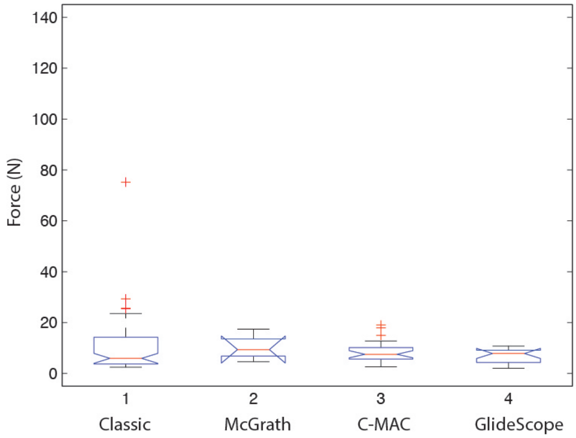


**Figure 6.5:** Average peak force for the lower teeth per laryngoscope. Averages are based on the selection of cases in which contact was made between teeth and blade (>2N).

The mean effective airway time was 8.6 ± 5.6 s for the patients in the DL group, compared to 18 ± 11 s in the McGrath group (p<0.001); 23 ± 16 s in the GlideScope

**Table 4:** Proportion of cases in which contact was made between the maxillary incisors and the blade and a force was applied (>2N).

| | N | Contact | Percentage | P-value |
|---|---|---|---|---|
| Macintosh laryngoscope | 141 | 93 | 66 | |
| McGrath® videolaryngoscope | 48 | 34 | 71 | |
| C-MAC® videolaryngoscope | 47 | 9 | 19* | p<0.001 |
| GlideScope® videolaryngoscope | 46 | 28 | 61 | |
| Total | 282 | 164 | 58 | |

** Significant difference between * and the other groups.*

group (p<0.001) and 11 ± 10 s in the CMAC group (not significant). In the latter group significantly more first attempt successful intubations were realized compared to the other two videolaryngoscope groups. In only 2/47 (4%) of the patients in the CMAC group, a stylet was needed to intubate the trachea, which was significantly lower than in the McGrath (29/48, i.e. 60%) and GlideScope (28/46, i.e. 61%) groups.

**Table 5:** Proportion of cases in which contact was made between the lower teeth and the blade and a force was applied (>2N).

| | N | Contact | Percentage | P-value |
|---|---|---|---|---|
| Macintosh laryngoscope | 141 | 73 | 52 | |
| McGrath® videolaryngoscope | 48 | 4 | 8* | <0.001 |
| C-MAC® videolaryngoscope | 47 | 24 | 51 | |
| GlideScope® videolaryngoscope | 46 | 14 | 30 | |
| Total | 282 | 115 | 41 | |

** Significant difference between * and the other groups.*

## DISCUSSION

6

This study confirms that when using videolaryngoscopy, the forces applied to the patient's maxillary incisors are reduced when compared with the classic Macintosh laryngoscope, while there are no differences in the forces exerted on the lower teeth.

The number of contacts made with the maxillary incisors was lowest with the C-MAC, whereas there were no differences in number of contacts between the other VLS studied and the classic laryngoscope. Average peak forces were lowest when using the C-MAC. The difference in average peak force between the C-MAC and the other VLS was not statistically significant. However, when unexpectedly, intubation was more difficult than anticipated (C&L grade III/IV), and for example the BURP (Backward Upward Right Pressure) manoeuvre had to be used or the help of an assistant was required, this did not result in differences between VLS concerning forces applied to the maxillary incisors.

When intubation could only be realized after multiple attempts, differences between numbers of contacts at each intubation attempt did exist. The trend seemed to be that providers made more contact at subsequent attempts. However, there was no clear increase in magnitude of forces applied to teeth.

The design of the C-MAC laryngoscope blade is similar to a classic Macintosh blade, but differs from the blades of the McGrath and GlideScope VLS. The fact that a videolaryngoscope with a Macintosh blade creates more room for intubation compared to other VLS, makes intubation not only easier (more room to direct/manipulate the TT and less use of stylets), but also faster (shorter effective airway time because the laryngeal and pharyngeal axes are more in one line compared to a videolaryngoscope with a curved blade, making the route, which the TT has to follow, more direct) and with less frequent contacts with maxillary incisors.

When using a classic direct laryngoscope with a Macintosh blade, all three axes (laryngeal, pharyngeal and especially oral) need to be positioned in one line. Often this requires the anaesthetist to use more force and so frequently more force is applied to the maxillary incisors.

The results of this study show a large difference between forces applied during direct and indirect laryngoscopy, with the mean force applied to the maxillary incisors being lowest for all measurements in the C-MAC group (i.e. 1.18 ± 4.73 N), which is comparable to the results of Lee et al.[4,6]

Patients were not intubated using the classic laryngoscope, and this could have affected the effective airway time realized by DL. The results on the forces obtained with the classic Macintosh laryngoscope may have been greater than the ones recorded. Actually passing the TT through the vocal cords could have turned out to be more difficult than just positioning it in front of the vocal cords, requiring more force to be used.

Limitations of the study include: 1) the restricted number of different brands of VLS in this study, since the number of available brands of VLS seems to increase daily; 2) this study only included patients with non-anticipated difficult airways, and hence nothing can be deduced for patients with difficult airways. One could argue if patients with a Mallampati score III can be considered as having a non-anticipated difficult airway. Indeed, this is often associated with a difficult airway. However, sometimes even a patient with a Mallampati I turns out to be difficult to intubate because of a high-anterior positioned glottis. The combination of exclusion criteria mentioned earlier and a cut-off value of Mallampati III is valid to exclude the majority of patients with a difficult airway. This was confirmed by the fact that all patients were successfully intubated; 3) we considered 2N as the lower range for determination of any force, which means that the actual number of contacts might be higher; and 4) actual intubation was only performed with the VLS, and hence intubation time could have been influenced for DL. Also, additional pressure may be applied and a higher number of contacts with the teeth may be experienced during actual passing of the TT between the vocal cords. This could have resulted in more contacts with teeth and greater force being applied to the teeth for the classic Macintosh laryngoscope; 5) a stylet was inserted into the TT to facilitate intubation only after two unsuccessful attempts. This may in part explain why a large proportion of the intubations required 3 - 4 attempts in the McGrath group (30/48 or 63% from Table 2) and the GlideScope group (28/46 or 61% from Table 2) even though the glottic views were good with both the McGrath and GlideScope (mostly with C&L grade I). In addition, this may also explain why the number of contacts made with the maxillary incisors was lowest with the C-MAC compared with the GlideScope and McGrath because of few attempts for tracheal intubation. We deliberately chose to only insert a stylet after two unsuccessful attempts, although the manufacturers of both GlideScope and McGrath recommend to always use a stylet. In our opinion, a stylet poses an extra risk of (oral) trauma to the patient.[7] We proved that even without a stylet intubation with GlideScope (39%) and McGrath (37%) is possible. Also, when we would have chosen to always use a stylet with the GlideScope and McGrath, we also should have always used one with the C-MAC, since the TT is easier to direct, making intubation more easily. Using a stylet with all VLS, as mentioned above, poses an extra risk to the patient. Also, this would have made intubating using the C-MAC far easier, possibly influencing outcome.

## CONCLUSIONS

Our study demonstrates that indirect video-assisted laryngoscopy results in significantly lower forces applied to maxillary incisors relative to classical DL in patients with no expected difficulty for intubation, and that there are differences among the VLS used. The number of contacts and forces applied to maxillary incisors significantly differs between the tested VLS. Forces applied to lower teeth seem clinically insignificant.

We strongly recommend considering using VLS in patients with poor dentition, dental crowns and/or fixed partial denture, needing intubation. When choosing a videolaryngoscope for this category of patients, the anaesthetist has to be aware of differences between VLS concerning risk of dental trauma.

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# Chapter 7

## Combined technique using videolaryngoscopy and Bonfils for a difficult airway intubation

Van Zundert AA, Pieters BM.

Br J Anaesth. 2012; 108: 327-8.

Editor—A difficult tracheal intubation can sometimes still be a problem, even if one has taken all precautions such as the evaluation of premetrics of a difficult airway, difficult airway trolley, and help from additional qualified personnel. The Backward Upward Right Pressure (BURP) manoeuvre[1] is usually the first technique applied when laryngoscopy reveals a Cormack and Lehane (C&L) grade III or IV, followed by the use of a number of adjuncts (gum elastic bougie, stylet) or different approaches of the airway (e.g. fibre-optic intubation, supraglottic airway, videolaryngoscopy). Nevertheless, even when all the above techniques have been applied properly, tracheal intubation still can be very challenging in the rare event that no part of the glottic entrance, nor the epiglottis can be seen.

We report our experience with a 45-yr-old woman (165 cm, 128 kg, BMI 48 kg $m^{-2}$, ASA class II, Mallampati grade IV, thyromental distance 51 mm, mouth opening 41 mm, short restricted neck) who presented for bariatric surgery (sleeve resection) under general anaesthesia. She had a past medical history of hypertension and diabetes mellitus and during a previous operation for removal of the right ovary (in another hospital), she had a prolonged and very difficult intubation, which eventually was successful using the LMA-Fastrach® as a conduit for tracheal intubation.



After discussing the anaesthetic options, the team and the patient agreed to proceed with general anaesthesia. After preoxygenation for 4 min, i.v. fentanyl 5 mcg $kg^{-1}$ and propofol 2.5 mg $kg^{-1}$ i.v. was administered. Before intubation, the lungs were manually inflated using face mask ventilation without problems. Rocuronium 0.1 mg $kg^{-1}$ was given i.v. and mask ventilation continued until the conditions were suitable for intubation of the trachea. This induction is in accordance with the routine practice in our hospital for bariatric surgical patients with the presence of the difficult airway trolley in the room. As we have been using the videolaryngoscope (C-MAC®, Karl Storz, Tuttlingen, Germany) for almost 3 years as our standard intubation technique, we also used it in this particular patient, revealing a C&L grade III, whereas the classic laryngoscope showed a grade IV. We easily intubated the trachea by using a combined technique, that is, the videolaryngoscope used to achieve the best possible view and space of the laryngeal inlet for the insertion and manoeuvring of the Bonfils® (Karl Storz, Tuttlingen, Germany), which was preloaded with the tracheal tube (TT). There is enough room next to the C-MAC to allow easy insertion of the Bonfils intubating fibrescope.[2,3] Once the Bonfils had entered the trachea, the TT was placed in the correct position. We organized it in such a fashion that both views were brought together on one monitor which normally is used by the surgeons (Figure 1), so that the intubation procedure could be seen by the whole team. This combined technique can be used for difficult tracheal intubation and can be one of many alternative routes to secure a safe airway for which anaesthetists should be trained in. The videolaryngoscope can also be helpful in presenting a better view for rigid bronchoscopy (respiratory physicians) or for ENT surgeons, who wish to inspect the oropharynx and larynx.


**Figure 7.1:** The combined use of videolaryngoscopy (left), presenting the best possible view of the larynx and epiglottis (Cormack and Lehane grade III) and Bonfils® intubating fibrescope using a railroading technique for intubation of a difficult airway, showing the tracheal rings (right).

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# Chapter 8

## Macintosh blade videolaryngoscopy combined with rigid Bonfils® intubation endoscope offers a suitable alternative for patients with difficult airways

Pieters BM, Theunissen M, van Zundert AA.

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## ABSTRACT

Background: In the armamentarium of an anaesthetist to secure the airway, videolaryngoscopy is a valuable addition. However, when the videolaryngoscope offers no solution, few options remain. Earlier, we presented an intubation technique combining Macintosh blade videolaryngoscope and Bonfils® intubation endoscope for a patient with a history of very difficult intubation.[1] In the present study we evaluated this technique to establish whether it is a valuable alternative.

Methods: In this single-blinded non-randomized study, 38 patients with a history of difficult intubation or one or more predictors of difficult intubation, scoring a Cormack and Lehane grade III or IV using a Macintosh blade videolaryngoscope, were included. Patients were intubated combining the videolaryngoscope with the Bonfils. The Cormack and Lehane grade was scored three times during: a) direct laryngoscopy; b) indirect videolaryngoscopy; and c) using the combined technique. Afterwards, two blinded anaesthetists assessed the Cormack and Lehane grade using the pictures taken during the procedure.

Results: Data of 38 patients were analysed. An improvement of the Cormack and Lehane grade with the combined technique occurred in 33 out of 38 patients (86.8%, 95% CI 71.9-95.6%). Reviewer 1 reported an improvement of the Cormack and Lehane grade with the combined technique in 37 out of 38 patients. Reviewer 2 reported improvement in 33 and deterioration in 2 of the patients. No complications occurred.

Conclusions: The combined use of a videolaryngoscope with Macintosh blade and Bonfils gives the anaesthetist a valuable alternative intubation option in patients with extremely difficult airways.

## INTRODUCTION

### Background and rationale

Earlier, Van Zundert and Pieters[1] reported on the successful application of a combined intubation technique (Figure 1), using indirect videolaryngoscopy and a rigid intubation endoscope, for a morbidly obese patient with a history of prolonged, very difficult intubation.[1] In most cases with a normal or difficult airway, using a videolaryngoscope will result in an improved Cormack and Lehane (C&L) grade, compared with classic direct laryngoscopy (DL). If, however, with the use of the videolaryngoscope still only the epiglottis is to be seen, the videolaryngoscope can be used to lift the epiglottis and combining its use with the rigid intubation endoscope may provide a valuable treatment option.

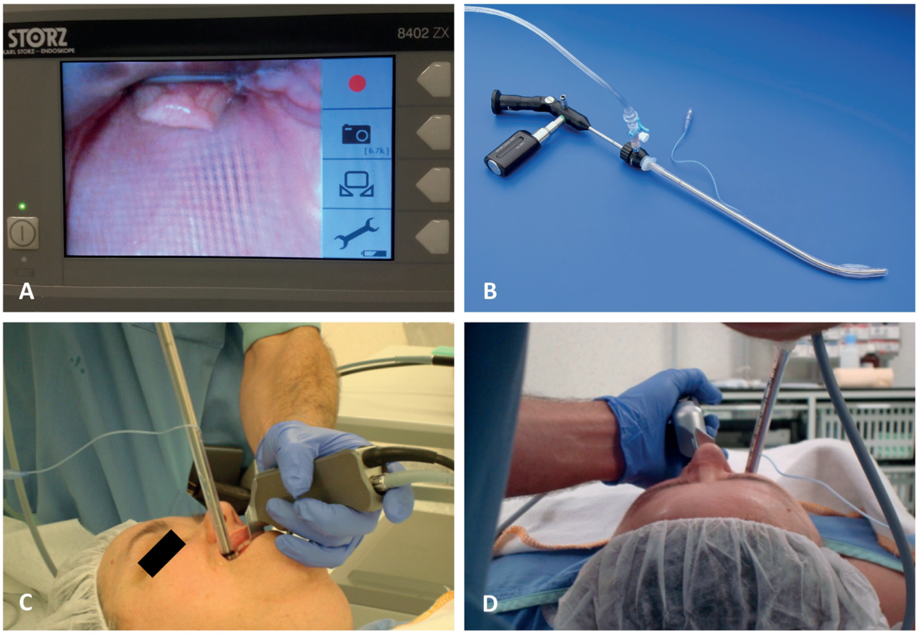


**Figure 8.1:** A. Videoscreen of an indirect Macintosh videolaryngoscope showing a C&L grade III; B. BIE loaded with a tracheal tube; C & D. Different angles of view showing the videolaryngoscope in the left hand and the BIE in the right hand.



### Study's objectives

The primary aim of this study was to assess visualization of the glottic entrance using the C&L grade scoring system in patients when indirect videolaryngoscopy failed to visualize (parts) of the vocal cords. The combined technique (indirect Macintosh blade videolaryngoscope and Bonfils® intubation endoscope (BIE) (Karl Storz, Tuttlingen, Germany)) was compared with the indirect Macintosh blade videolaryngoscope alone. Secondary aims were the first attempt successful intubation rate, time until successful intubation, number of attempts to successful intubation, trauma of the oral cavity, dental trauma, and the exploration of the effect of different predictors associated with difficult intubation on the intubation time.

## METHODS

Approval was obtained from the Institutional Review Board at the Catharina Hospital Eindhoven, The Netherlands (chairman Dr. R Grouls, COM 12.12-624). Written informed consent was obtained from all subjects. This single blinded non-randomized trial was registered at ClinicalTrials.gov (NCT01691703) and adheres to the applicable Equator guidelines.

### Patient population and inclusion/exclusion criteria

Patients, scheduled to undergo elective surgery under general anaesthesia at the Catharina Hospital Eindhoven, the Netherlands, with a history of difficult intubation, or one or more predictors of difficult intubation were selected for the study, after obtaining written informed consent. Enrolment took place during the pre-anaesthetic visit of the patient, performed by anaesthetists not involved in the study. Evaluation of the patients included age, height, weight, BMI, ASA classification, maximum mouth opening, thyromental distance, Mallampati score and dentition status. Inclusion criteria were: elective surgery needing tracheal intubation, age ≥18 years, a history of difficult intubation or one or more predictors of difficult intubation[2,3]: Mallampati grade III and IV, interincisor distance <30mm, restricted neck movement (<90°), thyromental distance <60mm or BMI >35 $kg.m^{-2}$. Exclusion criteria were no informed patient consent, age <18 years, emergency surgery, a previous intubation stated as “easy” / C&L grade I – II, fasted <6 hours, and head or neck surgery.

### Conduct of the study

Upon arrival at the operating theatre complex, patient characteristics were recorded, including all airway measurements mentioned above. Standard safety measures included monitoring of ECG, non-invasive blood pressure, oxygen saturation, train-of-four (TOF) ratio and intravenous access. Preoxygenation (3 min $FIO_2$ 1.0 by mask) was followed by induction of anaesthesia while the patient was placed in the supine, sniffing (external auditory meatus at the level of the sternal notch) position. Sufentanil (1.5 $\mu g.kg^{-1}$ lean body mass), propofol (2 mg.kg$^{-1}$ lean body mass) and rocuronium (0.6 mg.kg$^{-1}$ lean body mass) were administered to establish general anaesthesia.

Prior to intubation, the patient's lungs were manually ventilated using bag-mask ventilation and 100% oxygen, while sevoflurane was added as required. Muscle paralysis was measured using the TOF ratio, a TOF ratio of 0 was deemed as adequate for intubation. Depth of anaesthesia had to be evaluated as adequate by the anaesthetist, before any intubation attempts were performed. The two anaesthetists (investigators B.P. and A.v.Z.) intubating the patients in this study both had extended experience with DL as well as with videolaryngoscopy using a range of videolaryngoscopes (VLS), including the C-MAC® (Karl Storz, Tuttlingen, Germany). They both use VLS on a daily basis. A blade size 3 or 4 (left to the discretion of the anaesthetist) Macintosh videolaryngoscope was used to achieve the best possible laryngoscopy view and position in front of the laryngeal inlet. Once the anaesthetist considered the achieved view of the glottis to be the best possible (for example by applying – but not restricted to – external laryngeal pressure by an assistant), a picture was captured using the C-MAC SD card, not showing any part of the videolaryngoscope. Keeping the Macintosh videolaryngoscope in position using the left hand, the BIE, preloaded with the tracheal tube (TT) (size 7 for women and 8 for men) was brought into position in the mouth next to the Macintosh videolaryngoscope with the right hand, in front of the laryngeal inlet. The view obtained with the videolaryngoscope and the view obtained with the BIE were projected next to each other on one video monitor screen in regular use by surgeons for laparoscopic procedures. In this way, the anaesthetist was able to see both the view of the videolaryngoscope and the BIE on one screen (Figure 2). An image of the laryngeal view obtained with the BIE, not showing any part of one of the two devices was saved. Once the BIE was positioned in front of the tracheal entrance, the TT was passed into the correct position in the trachea. Subsequently, both the BIE and the Macintosh videolaryngoscope were removed from the patient's mouth, and the TT connected to the ventilator. Correct posi-

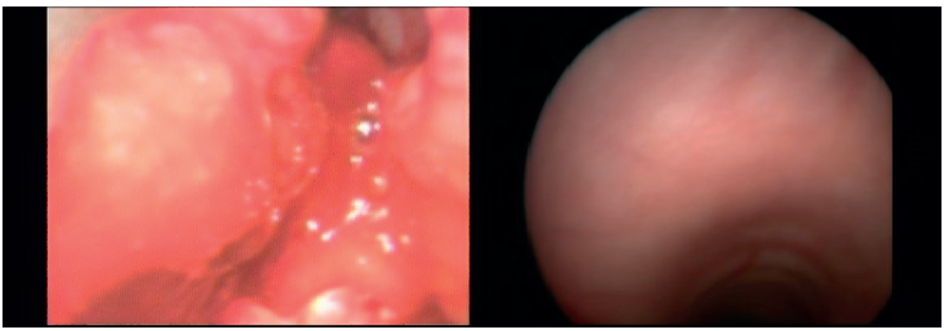

**Figure 8.2:** View of the videolaryngoscope (left) and the BIE (right) as seen simultaneously on one video monitor screen

tion of the TT was verified by normal capnogram, peripheral oxygen saturation (>95%) and auscultation of bilateral breathing sounds. The whole procedure was timed by the second investigator (not intubating the patient). Timing started when the Macintosh videolaryngoscope was placed between the teeth and ended when the TT was in the correct position showing the first capnogram.

### Outcome measures

Primary outcome measure was the C&L grade, evaluating the glottic view during tracheal intubation using classification grades I to IV.[4] The C&L grade was scored three times during the intubation by the intubating anaesthetist (investigators B.P. and A.v.Z.). First, to obtain a baseline value, the anaesthetist scored the C&L grade using the Macintosh videolaryngoscope for (classic) DL in the patient's mouth; second, using the Macintosh videolaryngoscope for indirect (video)laryngoscopy without removing it from the patient's mouth on the monitor of the videolaryngoscope; and finally, after the best possible view on the video monitor screen was achieved using the combination technique. To control for bias, after conclusion of the study, two independent anaesthetists, blinded for the used technique, additionally scored the C&L grade (indirect and with the combination technique) using the pictures recorded during the procedure in randomized order.

For the secondary outcomes, we collected data on: a) the number of first attempt successful intubations without the use of adjuncts; b) time until successful intubation; c) the number of attempts to successful intubation; and d) predefined complications including soft tissue (mucosal) trauma to the oral cavity, defined as any amount of bright red blood in the oral cavity, dental and lip trauma, and regurgitation observed by the anaesthetist. Furthermore, e) the use of adjuncts (e.g. gum elastic bougie, stylet and external laryngeal pressure (performed by a second operator)) was assessed.

### Data handling

Baseline and surgical data were retrieved from the patient's medical file, data concerning the intubation procedure were recorded by A.v.Z. and B.P. All data were collected using case report forms and entered in an SPSS database and checked by B.P. and M.T. All data and pictures were anonymized. Missing data were not imputed.

### Statistical analysis

Descriptive data analyses of baseline and outcome data were performed using mean (range), median (range) or number (%), where appropriate. For the primary outcome, a 95% confidence interval (CI) for the binomial probability (improved C&L score yes/no) was calculated according to the Clopper-Pearson method. The secondary assessment of C&L grade as defined by two independent anaesthetists (change in C&L grade with combination technique versus indirect technique, improved/unchanged/deteriorated) after judging the pictures is presented using a 3 by 3 table. The interrater agreement, using the kappa statistic, and the proportion of positive and expected agreement were calculated. The kappa statistic measures agreement or interrater reliability beyond that expected by chance.

For the secondary aim, the association between predictors of difficult intubation (e.g. Mallampati grade III-IV scores, BMI >35 $kg.m^{-2}$) and time until successful intubation was assessed. Statistical testing was performed using the Mann-Whitney test since the Shapiro-Wilk test revealed a non-parametric distribution. A significance level of $p < 0.008$ was used, based on a Bonferroni correction (0.05/6) for multiple testing.

Based on the findings of an earlier study,[5] we estimated an improvement in C&L grade in 75% of the cases after using the combination technique, compared to the use of the videolaryngoscope alone. With a planned number of 40 patients included and a confidence level of 95%, the 95% confidence interval would range from 62 to 88%.

Analyses were performed using SPSS (IBM SPSS 23, IBM Corporation, NY 10589, USA) and Stata 11.2 (StataCorp, Texas 77845 USA).

## RESULTS



After preoperative screening of 337 patients, a total of 42 patients with a history or one or more predictors of a difficult airway, were included across a six-month study period (Figure 3). Data of 38 patients were analysed, while 4 patients dropped out because indirect laryngoscopy using the Macintosh videolaryngoscope did not result in a C&L grade III or IV. All patients were successfully intubated.

Patient characteristics are depicted in Table 1. In total, 12 men (31.6%) and 26 women (68.4%) were included. Age (mean (SD)) of these patients was 50.2 (15.4) years and BMI 35.6 (12.9) $kg.m^{-2}$. Concerning predictors of difficult intubation, 17 patients (44.7%) had a BMI >35 $kg.m^{-2}$, 7 (18.4%) lacked adequate neck movement and a Mallampati score III/IV was scored in 19 (50%)/8 (21.1%) patients. Five patients (13.2%) had a history of difficult intubation and in 21 (55.3%) external features predicting a difficult intubation were present. In 23 patients, one predictor of difficult intubation was present, seven had two predictors, eight had three, four predictors were present in four patients and one patient showed five predictors.

All patients, except one, were successfully intubated using the combination technique. For the patient in whom the combination technique was not successful, intubation was

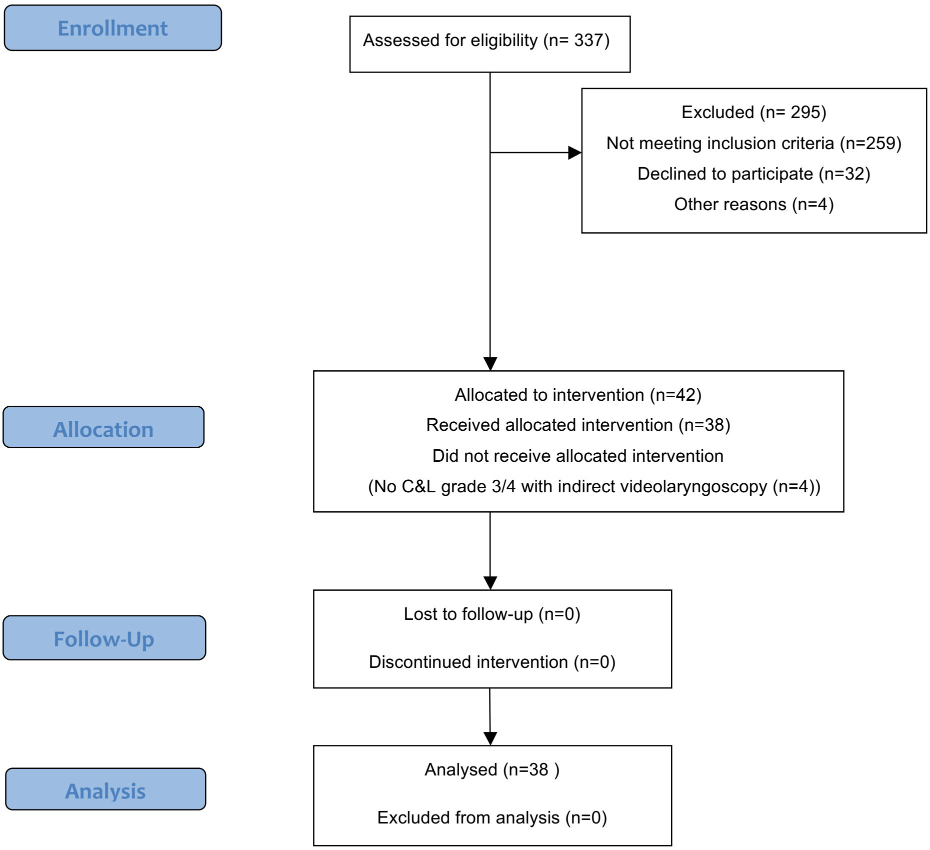


**Figure 8.3:** CONSORT Flow diagram

**Table 1:** Patient characteristics and intubation parameters.

| Parameter | Results |
|---|---|
| Age, years | 50.2 (15.4) |
| Height, cm | 169.6 (7.6) |
| Weight, kg | 102.8 (37.9) |
| BMI, kg.m$^{-2}$ | 35.6 (12.9) |
| Thyromental distance, mm | 60.8 (19.8) |
| Interincisor distance, mm | 37.1 (7.4) |
| ASA class, n (%), I:II:III | 11:23:4 (28.9%:60.5%:10.5%) |
| Mallampati score, n (%), I:II:III:IV | 6:5:19:8 (15.8%:13.2%:50.0%:21.1%) |
| Restricted neck movement <90°, n (%), y:n | 7:31 (18.4%:81.6%) |
| History of difficult intubation, n (%), y:n | 5:33 (86.8%:13.2%) |
| External features difficult intubation, n (%), y:n | 16:22 (42.1%:57.9%) |
| Dentition status, n (%), none: upper/lower: complete | 5:3:30 (13.2%:7.9%:78.9%) |

*Data represented as mean (SD), unless otherwise noted*
*Abbreviations: BMI, body mass index; ASA, American Society of Anesthesiologists*

achieved using the C-MAC D-Blade® (Karl Storz, Tuttlingen, Germany) instead of the Macintosh blade videolaryngoscope combined with the BIE.

Concerning the primary outcome, C&L grades that were scored by the intubating anaesthetist are presented in Table 2. When comparing indirect laryngoscopy with the combined technique, we found an improvement of the C&L grade with the combined technique in 33 out of 38 patients (86.8%, 95% CI 71.9-95.6%). The other 5 patients showed no improvement of the C&L grade, nor did it worsen. The C&L grade significantly improved when comparing direct to indirect laryngoscopy using the Macintosh videolaryngoscope. However, the improvement was, as hypothesized, even more when the combination technique was applied. As shown in Table 2, there were no C&L grade I and II scores with indirect (video)laryngoscopy, in contrast to the combination technique, where 86.8% of laryngoscopies resulted in a C&L grade I or II.

**Table 2:** Cormack and Lehane (C&L) grades scored by the intubating anaesthetist with classic direct laryngoscopy, indirect videolaryngoscopy and combination technique.

| C&L grade | Direct | Indirect | Combi |
|---|---|---|---|
| 1 | 0 | 0 | 32 (84.2%) |
| 2 | 0 | 0 | 1 (2.6%) |
| 3 | 16 (42.1%) | 34 (89.5%) | 3 (7.9%) |
| 4 | 22 (57.9%) | 4 (10.5%) | 2 (5.3%) |

*Data represented as number (%)*



Scores given by the independent, blinded reviewers concerning improvement of the C&L grade are depicted in Table 3. The prevalence of positive response (improved C&L score) was high, and the proportion of expected agreement was 84.8%, resulting in a paradoxally low kappa of -0.0364 (95% confidence interval -0.086 - 0.000). The proportion of positive agreement was 84.2%, of expected agreement 84.8%. However, one of the two reviewers scored a deterioration of the C&L grade twice.

**Table 3** Change in Cormack and Lehane (C&L) grade with combination technique versus indirect technique, scored by independent, blinded reviewers.

| | | **Change C&L grade Reviewer 1** | | | |
|---|---|---|---|---|---|
| | | Deteriorated | Unchanged | Improved | Total |
| **Change C&L grade Reviewer 2** | Deteriorated | 0 | 0 | 2* | 2 |
| | Unchanged | 0 | 0 | 3* | 3 |
| | Improved | 0 | 1* | 32 | 33 |
| | Total | 0 | 1 | 37 | 38 |

*Data represented as number*
**Disagreement between reviewers*

Mean [range] time to successful intubation was 30 seconds (s) [14-58]. Time to successful intubation was analysed in 37 instead of 38 patients. For one patient, instead of time to successful intubation, time of the complete surgical procedure was recorded. Time to successful intubation was evaluated taking into account the different factors associated with difficult intubation: Mallampati grade I and II versus III and IV, interincisor distance <30mm versus ≥30mm, restricted neck movement (<90°) (no versus yes), thyromental distance <60mm versus ≥60mm, BMI >35 $kg.m^{-2}$ versus ≤35 $kg.m^{-2}$ and a history of difficult intubation (no versus yes). Median [range] insertion time for patients without adequate neck movement was 44s [32-58], compared with 24s [14-58] for patients with adequate neck movement (p = 0.002) (Table 4). The rates for number of attempts until successful intubation were: one attempt 30 (78.9%), two attempts 5 (13.2%), three attempts 3 (7.9%).

No soft tissue trauma to the oral cavity, dental or lip trauma, and regurgitation occurred during the study period. Also, no adjuncts (e.g. gum elastic bougie, stylet and external laryngeal pressure) were used. All surgical interventions were uneventful.

**Table 4:** Time to successful intubation in seconds (s) taking into account the different factors associated with difficult intubation.

| | **Time (s)** Median[range] | **p-value** |
|---|---|---|
| Mallampati | | |
| I – II | 25[19-58] | 0.844 |
| III - IV | 25[14-58] | |
| Interincisor distance (mm) | | |
| < 30 | 24[21-58] | 0.851 |
| ≥ 30 | 25[14-58] | |
| Adequate neck movement | | |
| No | 44[32-58] | 0.002* |
| Yes | 24[14-58] | |
| Thyromental distance (mm) | | |
| < 60 | 32[20-58] | 0.031 |
| ≥ 60 | 23[14-58] | |
| BMI ($kg.m^{-2}$) | | |
| ≤ 35 | 24[14-58] | 0.851 |
| > 35 | 26[21-49] | |
| History of difficult intubation | | |
| No | 24[14-58] | 0.029 |
| Yes | 40[32-58] | |

*Data represented as median[range]*
**Significant results (p <0.008)*

## DISCUSSION

This is the first trial to investigate a tracheal intubation technique aimed at a group of patients presenting with a C&L grade III or IV while using indirect videolaryngoscopy. The combined technique presented reduced the intubation difficulty and resulted in improved laryngoscopy with a high first attempt and overall intubation success rate in the vast majority of cases, the mean time to successful intubation being no more than 30s. The obtained improvement in glottic view, as scored by the intubating anaesthetist, endured evaluation by two independent and blinded reviewers in nearly all cases.

Since its introduction, videolaryngoscopy has proven to be advantageous in a broad range of clinical situations and patients.[5-12] However, occasionally, intubation will fail with VLS.[12] In this case, the suggested combined intubation technique provides the anaesthetist with an alternative option.

An advantage of the combined technique is that the anaesthetist, less experienced with awake fibreoptic intubation, has an alternative technique to intubate the patient with an (expected) difficult airway. Since the patient is anaesthetized, the amount of psychological stress is far less for the patient (and the (less) experienced anaesthetist) compared with awake fibreoptic intubation. Furthermore, although this method was not specifically tested in emergency situations, it may also be considered a rescue approach. Finally, the avoidance of the use of different adjuncts for multiple attempts, lowers the risk of complications.



Other research supports techniques combining two devices. Lenhardt et al.[13] intubated 4 patients with cervical spine pathology who could not be intubated with a videolaryngoscope and rigid stylet, using an alternative method including a flexible fibrescope. There is an important difference between our technique and the technique described by Lenhardt et al. According to Lenhardt's technique, two people are necessary to keep a good glottic view: one to hold the videolaryngoscope in place, and the second person to proceed with the actual intubation with the flexible fibrescope, since it is extremely difficult to manage a flexible fibrescope using only one hand. This means that even a third person is needed, to pass the tube loaded on the flexible fibrescope, while the other two providers have to work together to keep a good view of the glottis. In the technique we describe, two people have to be involved, similar to the ideal situation for DL. One anaesthesia provider however, is able, without aid, to keep a good view of the glottis. Therefore, the combined technique makes keeping a good view of the glottis far easier.

Boker recently published a case series of 4 patients using the technique of combining a Macintosh videolaryngoscope with the BIE.[14] None of these patients however, are scored a C&L grade III or IV using indirect videolaryngoscopy. It is very well possible that they would have been successfully intubated when an indirect Macintosh videolaryngoscope was used alone.

The major strength of the present study is that we address a category of patients with a suspected difficult airway where the Macintosh videolaryngoscope does not offer the solution. The anaesthetist can decide to use this technique at any time during the intubation when confronted with an unexpectedly difficult intubation. No special measures have to be taken, except that the BIE needs to be connected to a separate video screen (e.g. a monitor normally used for minimally invasive surgery), but the image can also be viewed directly through the BIE, and no extra anaesthesia provider is needed.

Our study also has limitations. First, the BIE is not readily available in every centre. Second, because we only evaluated one type of videolaryngoscope, we cannot draw any conclusion for other VLS. The use of, for example, an acutely angled videolaryngoscope (e.g. C-MAC D-Blade®) could have resulted in a better C&L grade in some patients. Third, we used the Mallampati score as one of several predictors for difficult intubation. We are aware of the fact that this score has little diagnostic value, but indirect videolaryngoscopy resulted in a C&L grade III or IV. From this, it can be concluded that despite the use of the Mallampati score only patients with a difficult airway were included. Also, it is arguable if the C&L grading system is suitable for videolaryngoscopy. The C&L grading system was originally developed to support decision making during DL.[15] It was not developed for videolaryngoscopy. There are however no other good options. Alternatives would have been the intubation difficulty scale (IDS) proposed by Adnet et al.[16] or the POGO (percentage of glottic opening) score. However, for this study, use of the POGO score would imply a serious limitation, since all POGO scores with the videolaryngoscope would have been 0%. A solution is to refer to the quality of the view of laryngoscopy in terms of improvement or not. The cases in which there is no improvement of view with indirect videolaryngoscopy, are the cases addressed in this study. Fourth, blinding of the intubating anaesthetist was impossible. Bias of the intubating anaesthetist was probably present, since worsening of the laryngeal view was scored twice by one of the two reviewing anaesthetists. However, given the fact it only occurred in 2 of 38 evaluations, while at the same time the other reviewer and the intubating anaesthetist judged these two cases as improved, we consider this a small risk of bias. Fifth, 4 patients dropped out because indirect laryngoscopy using the Macintosh videolaryngoscope did not result in a C&L grade III or IV. Therefore, the study is two patients short of the a priori planned number. However, the lower border of the confidence interval of the proportion of improvement (71.9%) was almost as high as the estimated proportion in advance (75%) and significantly higher than the lower border estimated in advance (62%). Finally, it is hard to deduct anything regarding the learning curve for the technique presented. The use of the BIE is not readily intuitive, so we advocate gaining experience using the combined intubation technique. Simulation on manikins is warranted and since the extra impact of the combination technique on the patient and the risk for complications is low, it is a technique that can be used even when the intubation is unexpectedly difficult, offering a steep learning curve. Although no complications occurred during the present study, mechanical (equipment) failure, psychological factors (e.g. blood, fogging or secretions blurring the view) and trauma (e.g. sore throat, laceration of oral mucosa) may result in failure of the combination technique.

In conclusion, our results provide evidence that the combined use of indirect videolaryngoscopy with Macintosh blade and BIE can be a promising alternative technique for successful intubation of anaesthetized patients with a difficult airway.

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# Chapter 9

## Letters to the editor:

## 1) Measurement of forces during direct laryngoscopy and videolaryngoscopy

Pieters B, van Zundert A, Lee R.

Anaesthesia. 2012; 67: 1182-3.

Russell et al. measured the forces applied to the base of the tongue as a surrogate for the stress response[1], and showed that the peak lifting force on the base of the tongue during laryngoscopy is less with the GlideScope Cobalt® (Verathon, Bothell, WA, USA) videolaryngoscope compared with the direct Macintosh laryngoscope. The authors state that with the lack of prior research in this area (including the use of FlexiForce Sensors® (Tekscan Inc, Boston, MA, USA) technology in humans), they had no basis upon which to estimate the magnitude and variance of the results they were likely to encounter. This is surprising considering that we have previously used the same technology to measure the forces applied to the maxillary incisors by videolaryngoscopes (VLS) and the Macintosh laryngoscope.[2,3] We found that videolaryngoscopy results in less force applied to the maxillary incisors when compared with direct laryngoscopy (DL), but found no difference between VLS. It is therefore unsurprising to us that less force is applied to the soft tissues.

The clinical relevance of Russell et al.'s findings should be cautiously interpreted, as the blade has been modified with the addition of domed plastic 'pucks'. Essentially, the FlexiForce Sensors used in the study are relatively sensitive to the geometrical form of the loading. The addition of the 'pucks' by Russell et al. concentrates what would be a distributed contact load between the soft tissues of the base of the tongue and blade, thus increasing the 'point' load measured by the sensors. Although we suspect that the forces measured in this study are substantially lower than that which would induce trauma or laceration (and none was reported), the introduction of the 'pucks' does result in measurement of higher than actual forces.

As the authors state, factors that influence the force applied during laryngoscopy include the laryngoscopist's experience and technique, patient factors (e.g. mouth opening, length of maxillary incisors) and the application of manual in-line stabilisation.[1] Moreover, when comparing the GlideScope with the direct Macintosh laryngoscope, one is comparing blades with completely different designs. The blades differ geometrically, since the Macintosh blade has to bring the oral, pharyngeal and laryngeal axes into one line to accomplish a direct view of the glottis. One can imagine that this aligning of axes requires more force than with the GlideScope, which provides an indirect view of the glottis. We are aware that this is a great – if not the main – difference between a classic laryngoscope and a videolaryngoscope. However, VLS are available in many different designs and we believe it would be more appropriate to compare VLS with greater geometric similarity, e.g. the C-MAC® (Karl Storz, Tuttlingen, Germany), Coopdech® (Daiken Medical, Osaka, Japan) and McGrath MAC® (Aircraft Medical, Edinburgh, UK) on the one hand; and GlideScope and McGrath Series 5® (Aircraft Medical, Edinburgh, UK) on the other.

Lastly, we believe that the fact that intubation when using the GlideScope takes significantly longer should not be forgotten.[1,3] Previously it has been shown that mean arterial pressure increases progressively during the first 45 seconds of intubation with a straight laryngoscope blade[4], suggesting that prolonged intubation may cause a stronger stimulus to the airway, and thus a greater stress response.

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# Chapter 9

## Letters to the editor:

## 2) Use of the Macintosh laryngoscope for double-lumen tracheal tube placement

Pieters BM, van Zundert AA.

Anaesthesia. 2015; 70: 1094-5.

We read with interest the article by Yao et al.[1] comparing the McGrath Series 5® videolaryngoscope (Aircraft Medical, Edinburgh, UK) with the Macintosh laryngoscope for double-lumen tracheal tube (TT) placement. They recommend that in patients with a low airway risk index score requiring intubation with a double-lumen TT, the classic Macintosh laryngoscope is used as the initial device and the McGrath videolaryngoscope is used only if the classic Macintosh laryngoscope provides a poor glottic view.

We agree with the authors that in videolaryngoscopy, a good laryngoscopic view is not always associated with an easy intubation. However, we disagree with their recommendation to use the Macintosh laryngoscope as the first device in patients with a low airway risk requiring intubation with a double-lumen TT.

An ideal airway device is successful in both easy and difficult airway scenarios. Although the McGrath Series 5 videolaryngoscope has been designed for patients with difficult airways, using it does not necessarily result in an easy intubation despite a good view of the glottis. When a device is solely reserved for a difficult intubation, as proposed by the authors for the McGrath videolaryngoscope, the operator may not become familiar with it. Yao et al.'s findings are similar to those of Russell et al.[2], who showed that the GlideScope® videolaryngoscope (Verathon Inc, Bothell, WA, USA) was more difficult to use when placing a double-lumen TT, particularly for novices. As the authors state, experience with the McGrath videolaryngoscope for standard tracheal intubation is important for successful double-lumen TT placement. However, we question how novices should get sufficient experience with a device when it is solely reserved for a difficult airway situation.

We encourage the authors to repeat the study, comparing a videolaryngoscope with a Macintosh blade (e.g. the McGrath MAC® version; the C-MAC® (Karl Storz, Tuttlingen, Germany) or Coopdech VLP-100® (Daiken Medical Co, Osaka, Japan)) with the direct Macintosh laryngoscope. Videolaryngoscopes with Macintosh blades have the additional advantage of allowing both direct and indirect laryngoscopy.

Furthermore, it is important not to underestimate the clinical importance of malpositioning a double-lumen TT. A bulky version with a rigid stylet in situ may put a patient at risk for oropharyngeal trauma, especially when the intubator's view is hampered by the design of the videolaryngoscope. Cases of injury to the oropharyngeal space have been reported with the use of different videolaryngoscopes.[3-5] This is an important negative aspect of the device that has to be taken into serious consideration.

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# Chapter 10

## General discussion

General anaesthesia is administered daily in hospitals around the world, with more than 300 million surgical interventions being performed every year.[1,2] After induction of general anaesthesia, the patient is at risk of aspiration of gastric contents because normal airway reflexes (e.g. coughing, swallowing) are lost, which makes securing the patient's airway necessary.

Securing the airway is one of the most important parts of the anaesthetist's job. When the airway is easy to secure, after bag mask ventilation, the tracheal tube (TT) can be placed between the vocal cords using a laryngoscope. Placing a TT into the trachea is not always effortless and can be very challenging. The challenge of placing a TT starts with the fact that the human trachea was not 'designed' to be intubated. Usually there is no direct view possible and therefore instrumentation is required to achieve success. Despite the development of different devices to intubate the trachea, difficulties sometimes remain. When securing a patient's airway is difficult, the risk of morbidity and mortality exists.

Worldwide, anaesthetists have extensive experience with direct laryngoscopy (DL). This technique has developed over the centuries and has remained nearly unchanged since the beginning of the 20$^{th}$ century. During the 20$^{th}$ century however, laryngoscopy took a monumental leap forward with the entrance of flexible fibreoptic cables, enabling better illumination and visualisation of the glottic structures. The 1990s yielded the technological development of rigid fibreoptic endoscopy.[3] At the end of the 20$^{th}$ century, the collective efforts of many carried forward into the 2000s with the development of a range of videolaryngoscopes (VLS). Other developments, like the introduction of laryngeal masks (supraglottic airway devices) changed the world of airway management, the armamentarium of the anaesthetist and the way anaesthetists gain experience in airway management.



The aim of this thesis was to determine the position, added value and potential threats of videolaryngoscopy in the current world of airway management.

## Historical background

In Chapter 2, we determined the historical background of DL against which videolaryngoscopy was developed.

The first DL is often attributed to Alfred Kirstein in 1895. It took many years from the introduction of indirect laryngoscopy to the development of a direct laryngoscope, due to lack of an appropriate light source. Once an adequate light source was designed, various endoscopes were developed— firstly bronchoscopes, followed by gastroscopes, cystoscopes and laryngoscopes.[4] Chevalier Jackson was the first to describe the combination of direct visualisation of the larynx and tracheal intubation. In 1903, he designed his first laryngoscope, a U-shaped tubular instrument with a spatula and a tubal handle.[5]

Later he designed a laryngoscope blade with a distal light source. This light at the end of the blade was a unique contribution by Jackson. The light made it possible to directly visualize the larynx and so an important contribution was made to the development of laryngoscopy and by extension to tracheal intubation. However, DL did not gain in popularity among anaesthetists until Chevalier Jackson promoted the use of his hand-held laryngoscope for insertion of tracheal catheters.

World War I also played an important role in the evolution of DL and tracheal intubation. Two British anaesthetists, Sir Ivan Whiteside Magill (1888–1986) and Edgar Stanley Rowbotham (1890–1979), realised that reconstructive facial surgery performed on disfigured soldiers was easier and more successful under general anaesthesia with the airway secured by a TT.[6] The entrance of flexible fibreoptic cables enabled a gigantic evolution in laryngoscopy by means of better illumination and visualisation.[3]

Since the 2000s a wide spectrum of VLS with different physical and functional components exists. It is helpful to divide them into different categories to greater understand capabilities and functionality. One important distinction is the design of the blade. The blade can resemble a classic Macintosh blade (e.g. C-MAC® (Karl Storz, Tuttlingen, Germany)) or have a sharp angle of $60^0$ (e.g. GlideScope Cobalt® (Verathon Inc, Bothell, WA, USA)). The blade can be channelled or non-channelled. The introduction of indirect videolaryngoscopy brought laryngoscopy back to an indirect technique after a search for centuries for a direct technique.

## Position of videolaryngoscopy relative to classic direct laryngoscopy

The introduction of VLS resulted in many studies evaluating their proposed clinical value. Several publications showed that videolaryngoscopy can be valuable in obese patients,[7] emergency airway management,[8] in reducing the risk of dental trauma,[9] as rescue devices for unexpected, difficult airways,[10] and most significantly, may decrease the number of difficult intubations.[11] Nowadays, despite the extended experience of anaesthetists with DL, difficult, delayed and failed intubation as well as 'can't intubate can't ventilate' (CICV – or can't intubate can't oxygenate (CICO)) still accounts for 39% of all events during anaesthesia.[12] For a new technique of intubation to be successful, it should have an additional value to the existing technique.

The aim of Chapter 3 was to determine if the added value of videolaryngoscopy over DL remains when anaesthetists with extended experience with classic DL use videolaryngoscopy for patients with a known difficult airway.

We set up a systematic review and meta-analysis and identified studies evaluating the use of VLS by experienced anaesthetists. These were, amongst others, evaluated on terms of success of first time intubation attempt, time to successful intubation and view of the glottis. Our systematic review and meta-analysis showed a significantly greater success of first time intubation for the use of VLS. This is important, since the risk of complications increases when more intubation attempts are made.[13] Repeating the attempt at tracheal intubation increases the risk of progression to a CICV/CICO situation[12] and the American Society of Anesthesiologists' Closed Claims Project (ASACCP) analysis suggested an increase in death and brain damage in such cases.[14] When DL is unsuccessful, further attempts with the same technique have a close to 80% failure rate while alternative techniques (e.g. videolaryngoscopy) are more successful.[19] Our results differ from those of Lewis et al.[15], who found a reduction in the number of failed intubations, but not in the number of intubation attempts. This may be explained by the fact that their review was not limited to patients with a known difficult airway, and did include patients with a simulated difficult airway. Similar to our results, Griesdale et al.[16] found a greater success of first intubation attempt, but this was confined to nonexpert operators only. We found no association between the use of videolaryngoscopy and a shorter time to successful intubation. This is in accordance with Griesdale et al.; they only found a shorter time to intubation when the GlideScope was used by nonexpert users.[16]

The implication of these results is that videolaryngoscopy has added value, even for anaesthetists with extended experience with DL. Anaesthetists familiar with DL sometimes seem to be somewhat reluctant to use videolaryngoscopy. Arguments by experienced clinicians have been linked to opinions on device size, lack of experience, and lack of comfort in clinical settings; all of which contribute to diminished faith in VLS and an unwillingness to use the devices. In our meta-analysis, videolaryngoscopy resulted in a significantly improved view of the glottis. The number of laryngoscopies resulting in a Cormack and Lehane (C&L) grade III or IV was significantly less when using videolaryngoscopy in general and VLS with acutely angled blades in particular. VLS with an acutely angled blade ask for another technique of intubation; the shape of the blade follows the natural anatomy of the oral cavity. The acutely angled or curved blade can actually be a handicap, especially for experienced anaesthetists being relatively inexperienced with videolaryngoscopy. The experienced anaesthetist, familiar with the act of DL, will subconsciously try to bring the oral, pharyngeal and tracheal axes in one line.[17] Doing so could hamper the intubation when using a videolaryngoscope with an acutely angled blade.



### Different videolaryngoscopes for different users

The ideal device should provide a distinctive advantage when encountering a difficult airway, while at the same time not hampering an easier, normal laryngoscopy. A device that meets these criteria should be used for every patient, moreover since repeated use of a device shortens the time to achieve expertise. In Chapter 4 we investigated whether VLS of different manufacture are superior when compared to others for users with different levels of experience when confronted with patients with a normal airway.

Since videolaryngoscopy was introduced, it has primarily been reserved for difficult intubations. In our study, for a manikin with a normal airway, all groups were fastest using VLS with a Macintosh-type blade. Like mentioned before, a device for laryngoscopy should have additional value for the difficult airway, but should never hamper a normal laryngoscopy. The ideal videolaryngoscope combines the benefits of conventional Macintosh blade DL and videolaryngoscopy in one device. This way advantage can be taken of the experience gained over the years, making the concept of laryngoscopy technique intuitively familiar to providers, whilst also offering something extra for the difficult laryngoscopy.[20] We found that all groups, even experienced anaesthetists, needed significantly more attempts using the Airtraq® (Prodol, Vizcaya, Spain) and Pentax AWS® (Pentax Corporation, Tokyo, Japan), which are both channelled, acutely angled videolaryngoscopes. This is in line with previous results showing that it is more difficult to teach 'acutely angled' videolaryngoscopy to experienced Macintosh users than to novices.[21] In our study, medical students without experience in DL, needed significantly more attempts when using the classic Macintosh laryngoscope. This reflects the results shown in previous studies; after 1-43 attempts at tracheal intubation, most novices had a ≥80% success rate within two attempts per patient.[18] Experience with DL does not equate to skill with videolaryngoscopy and being skilled in the use of one videolaryngoscope does not automatically make one skilled with all VLS.[19] Devices with a Macintosh-type blade (classic laryngoscope and C-MAC) scored highest in user satisfaction. Our results underline the importance of variability in device performance across individuals and staff groups, which have important implications for which devices hospital providers should rationally purchase.

## Complications associated with videolaryngoscopy

When choosing a videolaryngoscope, the user should always take into account the patient the videolaryngoscope will be used for. A high rate of first attempt successful intubations should never come at the cost of more complications for the patient. In the previous chapters, we already proved that differences exist between different VLS, e.g. intubation success, laryngeal view and user satisfaction. In Chapter 5 and 6 we showed that differences between VLS also exist concerning the risk for complications.

During tracheal intubation patients are more or less at risk for dental trauma. The anaesthetist has to avoid using the maxillary incisors as a fulcrum to lever the soft tissues upwards, since this may otherwise result in dental trauma. Contact with teeth and – even worse – dental trauma, are directly related to the experience of the person intubating the patient, but to also the difficulty of the intubation.[22]

To see if a difference in risk for dental trauma between direct and video laryngoscopy exists, we investigated the magnitude of forces applied to the maxillary incisors during DL and videolaryngoscopy using Flexiforce® sensors (A201-25, Tekscan, MA, USA). We found forces exerted on maxillary incisors were lower using videolaryngoscopy compared to classic DL. Among the VLS tested, the average force applied was significantly lower for the videolaryngoscope with a Macintosh shaped blade as compared to VLS with acutely angled blades. The frequency with which a force was applied to the maxillary incisors was also significantly lower for the Macintosh blade videolaryngoscope, compared to both the other VLS and the classic Macintosh laryngoscope. These results are in accordance with earlier research[23] and show the benefit of videolaryngoscopy for patients in terms of safety. These results also have educational implications. Avoiding using the maxillary incisors as a fulcrum is especially difficult for inexperienced intubators. When people, being trained in (direct) laryngoscopy, have the deposition of a Macintosh blade videolaryngoscope, they can learn to master the skill of tracheal intubation while exposing the patient to significant less risk of dental trauma. On top of that, the supervisor can have a perfect view of what the trainee is doing.

New devices come with their own risks and potential hazards and anaesthetists should be aware of these. When experience is lacking, the use of new devices can result in greater risks for the patient. For VLS, complications like soft palate perforation have been reported.[24,25] In Chapter 5 we give an explanation for the appearance of these complications. We proved that VLS differ in the amount of illumination of the oral cavity. Certain devices (e.g. Pentax AWS) illuminate the oral cavity of a manikin 40 times less compared to other VLS. This is especially important when VLS (e.g. GlideScope) have to be used with different adjuncts (like a rigid stylet), turning the TT into a much sharper device, with which the anaesthetist is manoeuvring in the dark. Meanwhile, whilst looking at the screen of the videolaryngoscope (instead of in the patient's mouth), the risk for trauma increases. Suboptimal illumination of the oral cavity becomes an even more important factor when the user is less experienced with videolaryngoscopy, and does not have perfect eye-hand coordination. Here too, the importance of practice needs to be highlighted. Studies evaluating training of laparoscopic skills for surgeons showed that repeated practice is of utmost importance.[26] There is no reason to suspect this to be different for anaesthetists.



## Extended possibilities of videolaryngoscopy

The very difficult airway remains within the domain of the expertise of the anaesthetist. Does combining the videolaryngoscope with a rigid intubation endoscope provide the anaesthetist with a trustworthy and valuable alternative intubation technique when confronted with patients with a very difficult airway? This question was addressed in Chapter 7 and 8 of this thesis.

New devices come with new opportunities. Exploring the possibilities of VLS can offer a whole lot of extra options, improving the chances of making every encounter with a difficult airway a successful one. VLS can be combined with other, older devices to provide the anaesthetist with more tools to control the (unexpectedly) difficult airway. We combined the use of a Macintosh blade videolaryngoscope with the Bonfils® intubation endoscope (Karl Storz, Tuttlingen, Germany). First, we reported on the successful application of this combined intubation technique for a morbidly obese patient with a history of prolonged, very difficult intubation (Chapter 7). To evaluate if this case was not a fluke, we evaluated the technique in 38 consecutive patients with known difficult airways. All patients, except one, were successfully intubated using the combination technique with the mean time to successful intubation being only 30 seconds and no complications occurred. An improvement in the view of the glottis was achieved in the majority of patients, and this improvement endured evaluation by two independent and blinded reviewers in nearly all cases (Chapter 8). In this study, we address a category of patients with a suspected difficult airway where the Macintosh videolaryngoscope does not offer the solution, but the combined technique provides another option for intubation. The technique we present has important added value compared to combined techniques proposed by others. Lenhardt et al.[27] used an alternative method including a flexible fibrescope. In contrast to our technique, their technique requires three people. Boker et al[28], described 4 patients of which none scored a C&L grade III or IV using indirect videolaryngoscopy. It is very well possible that their patients, unlike ours, would have been successfully intubated when an indirect Macintosh videolaryngoscope was used alone.

## Implications for the future

The 2015 Difficult Airway Society (DAS) guidelines recommend that every anaesthetist has acquired skills of videolaryngoscopy and that all anaesthetists have direct access to a videolaryngoscope at all times.[10] This recommendation highlights two important points: training and direct access.

To become trained in videolaryngoscopy, one requires instruction, training and practice. According to evidence, difficult airways occur in 5.8% of the general anaesthesia population[29], so we estimate that the average anaesthetist (e.g. in Dutch clinical settings) will encounter a maximum of about two difficult airway management cases per month (i.e. assuming an average of 10 intubations per week, or 2 per day). This estimation considers working with residents, nurse anaesthetists and the reduction of the exposure to laryngoscopy at the background of the increase of the modern, widespread use of supraglottic airway devices.[30] Earlier, it was determined that at least 76 intubations were necessary to reach expertise with the GlideScope videolaryngoscope for anaesthetists experienced with direct Macintosh laryngoscopy, so practice is indispensable.[30]

Yao et al.[31] evaluated the use of the McGrath Series 5 videolaryngoscopes for the placement of double lumen TT. They advise to limit the use of VLS for patients with a high airway risk index score. When a device is solely reserved for the occasional difficult intubation, the operator may not obtain the clinical mileage to develop clinical proficiency. This poses a clear risk in difficult airway situations and further underlines the prospective importance of using devices that are compatible for use in both normal and difficult airways scenarios, giving the healthcare provider a safe way to practice more regularly. The best available intubation methods should not be reserved only for the most difficult cases (Chapter 9.2). Our estimation is that the average, experienced anaesthetist will need a period of 1-5 years to achieve expertise if videolaryngoscopy is solely reserved for difficult airways. This hypothesis is based on the requirement that anaesthetists will intubate 10 patients per week and encounter two difficult laryngoscopies per month whilst utilizing the same videolaryngoscope every time.[29]

In terms of patient safety this is a very undesirable situation. To increase patient safety, not only every resident in anaesthesia, but also every anaesthetist, should be trained in videolaryngoscopy and acquire a sufficient competency level. We propose a minimum of at least 150 normal airway cases and 75 difficult airway cases (for example C&L grade III/IV with DL) in terms of training.

The anaesthesia community should take initiative and responsibility in the quest for the most suitable videolaryngoscope(s).[32] This quest should not be limited to the operating theatre, but also expanded to the Intensive Care Unit, the emergency room and pre-hospital airway management.

Anaesthetists should continue to maintain active responsibility towards the development of pre-clinical and clinical research. Their stance promotes the continual development of newer devices and critical evaluation of currently available VLS; placing particular focus on improvement of the best available devices. Development and choice of device should be tailor made. Important selection criteria are the user's current intubation technique of choice, expected use of the videolaryngoscope, current way of dealing with an (unexpected) difficult airway, main patient characteristics (e.g. head and neck oncology, paediatric), use for teaching, and budget. The best choice for the experienced anaesthetist seems to be a direct (classic) Macintosh blade videolaryngoscope. This videolaryngoscope should respect the extended experience with DL, and this experience should never be a handicap. Ideally the device has interchangeable blades which are small relative to the oropharynx (not channelled) and easy to sterilize.



The experience gained over the years with DL should be treasured, not discarded. At the same time, open mindedness with a healthy amount of criticism towards new developments should exist. Anaesthetists must be willing to embrace new opportunities that come with new devices in terms of patients' safety and education of the next generation. With new opportunities, the user has to take account of the possible pitfalls, to maximise the benefit.

The evidence definitively speaks in favour of the videolaryngoscope: anaesthetists should make the distinction. To begin with, the focus should be on 1) education – the minimum amount of training in videolaryngoscopy required must be established; 2) selection – VLS should be compared to find the best suitable device for specific situations (e.g. daily practice, difficult airway management, use out of hospital) and the added value of videolaryngoscopy and different VLS for paediatric airway management should be established; 3) threats – the disadvantages of different devices must be investigated and compared; 4) position – is videolaryngoscopy the new gold standard?

Videolaryngoscopy has made the life of anaesthetists much easier and contributes to patient safety. It is now our duty to create the optimal circumstances to implement videolaryngoscopy and make it available to all colleagues and offer it to all patients, always.

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# Chapter 11

## 1) English summary

Airway management is one of the mayor tasks of the anaesthetist, either in or outside the operating theatre. When a patient loses consciousness, the airway needs to be secured to protect the patient from aspiration of gastric contents and to make spontaneous or mechanical ventilation possible. A secured airway can be achieved by placing a tracheal tube (TT) between the vocal cords of the patient. The most common way to do this is to perform direct laryngoscopy (DL), achieving a direct view of the vocal cords and thus placing the TT under direct sight. Correctly placing a TT however, is not always obvious and can be a challenging task.

**Chapter 2** describes the development of airway management from early history until today. Centuries ago, one only had the deposition of bulky instruments to get an indirect view of the glottis. Instruments lacked a direct light source, so illumination of the oral cavity and glottis was the biggest obstacle. Only when a direct light source was developed, many different endoscopes were designed.

Late in the 19th century, a direct view of the glottis could be obtained with various direct laryngoscopes, but it was not until World War I that tracheal anaesthesia became increasingly popular and the technique of DL followed by intubation of the trachea was further optimized. Laryngoscopy improved with the development of flexible fibreoptic cables enabling a much better visualization and illumination of the larynx for both direct and indirect laryngoscopy. In the early 21st century, there has been a return to indirect laryngoscopy via videolaryngoscopy using different videolaryngoscopes (VLS). VLS can differ greatly; they can roughly be divided into two groups: channelled and non-channelled. The non-channelled devices can then further be divided in angulated and non-angulated.

With the introduction of different VLS, the question rose what advantage they have over (classic) DL. After all, the experience gained over decennia with DL should not be underestimated. To find an answer concerning the added value of videolaryngoscopy for anaesthetists confronted with patients with a known difficult airway, a systematic review and meta-analysis is presented in **Chapter 3**. After systematically searching PUBMED, MEDLINE, EMBASE and the Cochrane central register of controlled trials we included 9 studies. Analysis of these 9 studies showed that videolaryngoscopy was associated with greater first intubation attempt success. The use of VLS was not associated with a shorter time to successful intubation, but did result in a significantly improved view of the glottis and less mucosal trauma. This meta-analysis shows that videolaryngoscopy has an added value for experienced anaesthetists. Future research should make it possible to make recommendations about which device should be used for which patient, taking into account the patient's condition and the background and experience of the videolaryngoscope user.

For a device to become the new gold standard in airway management, it should offer advantages in difficult tracheal intubations while not jeopardising non-difficult tracheal intubations. Videolaryngoscopy is often reserved for 'anticipated' difficult airways.

In **Chapter 4**, we observed 65 anaesthetists, 67 residents in anaesthesia, 56 paramedics and 65 medical students, intubating the trachea of a standardised manikin model with a normal airway using eight devices: Macintosh classic laryngoscope, Airtraq®, C-MAC®, Coopdech VLP-100®, C-MAC D-Blade®, GlideScope Cobalt®, McGrath Series 5® and Pentax AWS® in random order. The aim was to give an indication on which device would be most suitable for which healthcare provider.

The main observation was that, for the very wide range of devices tested, across all key groups, there was not one single device that was best for all caregivers. However, all groups were fastest using devices with a Macintosh-type blade, but needed significantly more attempts using the Airtraq and Pentax AWS (all $p < 0.05$). Devices with a Macintosh-type blade (classic laryngoscope and C-MAC) scored highest in user satisfaction. This chapter points out that a balance between the advantages of VLS and the disadvantage of new skill requirements can be found in VLS with a classic-shaped Macintosh blade (e.g. C-MAC and Coopdech VLS). These results underline the importance of variability in device performance across individuals and staff groups, which have important implications for which devices hospital providers should rationally purchase. The choice of a laryngoscope should be made based on requirements of the device and the person using it.

VLS make tracheal intubation possible without extensive experience. Good to perfect visualisation of the oral cavity is one of the main features of videolaryngoscopy. An important but underestimated aspect influencing visualisation is lighting. A clear visibility of the oropharynx and laryngeal entrance and the availability of substantial space in the mouth for manoeuvring a TT and other adjuncts (e.g. gum elastic bougie, stylets, oro/nasogastric tube, Magill forceps) are keys to success. Although less than optimal illumination does not have to result in unsuccessful tracheal intubation, the risk of trauma remains.

In **Chapter 5**, the intensity of illumination from the light source of different VLS was compared. Devices were compared in a photographer's dark room, an operating theatre and outside in bright sunlight. The intensity of light was measured at the oral cavity opening of a Laerdal® intubation trainer. Measurements of luminance differed substantially among devices. Illumination was best when using the C-MAC videolaryngoscope. Comparing our results with the recommendations made previously for DL (a minimum required luminance of 100 cd/m$^2$), illumination was poor with all VLS tested, except for the C-MAC when used in the operating theatre. It is important that clinicians are aware of these possible shortcomings and differences between devices.

Further exploring the advantages of videolaryngoscopy, we investigated in **Chapter 6** whether three different brands of VLS, i.e. McGrath series 5, C-MAC and GlideScope Cobalt, apply reduced forces on both maxillary incisors and lower teeth, and compared them with a classic Macintosh laryngoscope. It has been demonstrated previously that the forces applied to the patient's maxillary incisors are reduced, compared to a classic Macintosh laryngoscope, when using a videolaryngoscope. However, previous studies only evaluated one type of videolaryngoscope, or different types than the ones we used and forces on lower teeth were not investigated. In this chapter, it was confirmed that when using videolaryngoscopy, the forces applied to the patient's maxillary incisors are reduced when compared with the classic Macintosh laryngoscope, while there are no differences in the forces exerted on the lower teeth. The number of contacts made with the maxillary incisors was lowest with the C-MAC, whereas there were no differences in number of contacts between the other VLS studied and the classic laryngoscope. Average peak forces were lowest when using the C-MAC. Based on this result, it is strongly recommended to use videolaryngoscopy in patients with poor dentition, dental crowns and/or fixed partial denture, needing intubation. When choosing a videolaryngoscope for this category of patients, the anaesthetist has to be aware of differences between VLS concerning risk of dental trauma.

On top of the advantages addressed in the previous chapters, videolaryngoscopy can offer new opportunities in the field of airway management. In **Chapter 7**, we present a new successful intubation technique, combining a Macintosh blade videolaryngoscope with a Bonfils® intubation endoscope (BIE) for a patient with a history of very difficult intubation. In **Chapter 8** we evaluated this technique to establish whether it is a valuable alternative. We included 38 patients with a history of difficult intubation or one or more predictors of difficult intubation, scoring a Cormack & Lehane (C&L) grade III or IV using Macintosh blade videolaryngoscopy. Patients were intubated combining the videolaryngoscope with the BIE. The C&L grade was scored three times during: a) DL; b) indirect videolaryngoscopy; and c) use of the combined technique. Subsequently, two anaesthetists, blinded for the intubation technique used, assessed the C&L grade using the pictures taken during the procedure. The combined technique reduced the intubation difficulty and resulted in improved laryngoscopy with a high first attempt and overall intubation success rate in the vast majority of cases, the mean time to successful intubation being no more than 30 seconds. The obtained improvement in the glottis view, as scored by the intubating anaesthetist, endured evaluation by two independent and blinded reviewers in nearly all cases.

The combined intubation technique provides the anaesthetist with an alternative option when confronted with difficult intubation conditions. Nowadays, most anaesthetists will rely on a videolaryngoscope when confronted with a difficult intubation.

However, when the patient is already anaesthetized and videolaryngoscopy results in an unexpected C&L grade III or IV, only a limited number of options remain. Advantages of the combined technique are; 1) less stress for the patient compared with awake fibreoptic intubation (since the patient is anaesthetized); 2) the technique may be considered as a rescue approach; and 3) the avoidance of the use of different adjuncts for multiple attempts, lowers the risk of complications. These results provide evidence that the combined use of Macintosh blade videolaryngoscopy and BIE can be a promising alternative technique for successful intubation of anaesthetized patients with difficult airways.

In **Chapter 9.1** we point out that the conclusion "the peak lifting force on the base of the tongue during laryngoscopy is less with the GlideScope Cobalt compared with the direct Macintosh laryngoscope" as given by other researchers, is in concordance with our previous finding that videolaryngoscopy results in less force applied to the maxillary incisors when compared with DL (Chapter 6). However, their conclusion should be cautiously interpreted, as the blade of the videolaryngoscope tested has been modified resulting in the possible measurement of higher than actual forces. Moreover, when comparing the GlideScope videolaryngoscope with the direct Macintosh laryngoscope, it is important to realize that two devices are compared with completely different blade designs.

In the Letter-to-the-Editor presented in **Chapter 9.2** we disagree with the statement to use the Macintosh laryngoscope as the first device in patients with a low airway risk score requiring intubation with a double-lumen TT and reserve the McGrath videolaryngoscope only for patients with a high airway risk score. When a device is solely reserved for a difficult intubation, the operator may not become familiar with it. The importance of regular and sustained practice cannot be underestimated.

**Chapter 10** focusses on the general discussion concerning the outcome of our research. The position of videolaryngoscopy relative to DL is addressed, as well as the importance for users to be aware of the need for training with VLS, the differences between VLS and the potential advantages, disadvantages and specific complications that can result from the use of different VLS. Furthermore, in Chapter 10, we focus on the extended possibilities of videolaryngoscopy and its implications for the future.

Finally, a summary in English and Dutch is given in **Chapter 11** to highlight the most important findings of this thesis.

# Chapter 11

## 2) Nederlandse samenvatting

Luchtwegmanagement is een van de belangrijkste taken van de anesthesioloog, zowel in de operatiekamer als daarbuiten. Wanneer een patiënt onder anesthesie wordt gebracht, moet de luchtweg worden veiliggesteld om de patiënt te beschermen tegen aspiratie van maaginhoud en om spontane of mechanische ventilatie mogelijk te maken. Een veilige luchtweg kan worden bewerkstelligd door een tracheale tube (TT) tussen de stembanden te plaatsen. De meest gebruikte manier om dit te bereiken is door middel van directe laryngoscopie (DL). Hiermee kan direct zicht op de stembanden worden verkregen zodat de TT onder direct zicht in de trachea kan worden geplaatst. Het correct plaatsen van een TT is echter niet altijd vanzelfsprekend.

**Hoofdstuk 2** beschrijft de ontwikkeling van luchtwegmanagement vanaf de vroegste geschiedenis tot nu. Eeuwen geleden had men alleen de beschikking over grote, kolossale instrumenten om een indirect zicht op de glottis te kunnen krijgen. Instrumenten misten een directe lichtbron, waardoor verlichting van mondholte en glottis het grootste obstakel was. Pas toen directe lichtbronnen werden ontwikkeld, konden veel verschillende endoscopen worden ontworpen.

Eind 19e eeuw was men in staat een direct zicht op de glottis te krijgen met verschillende directe laryngoscopen. Het was echter pas na de Eerste Wereldoorlog dat anesthesie gecombineerd met tracheale intubatie steeds populairder werd en de techniek van DL gevolgd door tracheale intubatie verder werd geoptimaliseerd. De ontwikkeling van flexibele fiberoptische kabels zorgde ervoor dat laryngoscopie verder kon worden ontwikkeld. Zowel tijdens directe als indirecte laryngoscopie kon de larynx veel beter worden verlicht en zichtbaar gemaakt. Aan het begin van de 21ste eeuw zorgde de introductie van verschillende videolaryngoscopen (VLS) voor een terugkeer naar de indirecte laryngoscopie. VLS verschillen onderling sterk; ze kunnen ruwweg verdeeld worden in twee groepen: met en zonder voorgevormd kanaal voor de TT. De VLS zonder voorgevormd kanaal kunnen weer worden ingedeeld in VLS met een blad met acute hoek en VLS met een Macintosh vormig laryngoscoopblad.



Met de introductie van verschillende VLS rees de vraag welk voordeel zij over (klassieke) DL hebben. Immers, de ervaring die over decennia met DL is opgedaan, moet niet worden onderschat. Om een antwoord te vinden ten aanzien van de toegevoegde waarde van videolaryngoscopie voor anesthesiologen die geconfronteerd worden met patiënten met een bekende moeilijke luchtweg, wordt in **Hoofdstuk 3** een systematische review en meta-analyse gepresenteerd. Na systematisch literatuuronderzoek van PUBMED, MEDLINE, EMBASE en het Cochrane central register of controlled trials hebben we 9 studies geïncludeerd. Analyse van deze 9 studies toonde aan dat videolaryngoscopie is geassocieerd met een hogere mate van succes van de eerste intubatie poging. Het gebruik van VLS was niet geassocieerd met een kortere tijd tot succesvolle intubatie, maar resulteerde wel in een significant verbeterd zicht op de glottis en minder oromucosaal trauma. Deze meta-analyse laat zien dat videolaryngoscopie een toegevoegde waarde heeft voor ervaren anesthesiologen. Toekomstig onderzoek zou het mogelijk moeten maken om aanbevelingen te doen over welke videolaryngoscoop moet worden gebruikt voor welke patiënt, rekening houdend met de conditie van de patiënt en de achtergrond en ervaring van de gebruiker.

Een apparaat dat de nieuwe gouden standaard in luchtwegmanagement wordt, moet voordelen bieden bij moeilijke tracheale intubaties, zonder de niet-moeilijke tracheale intubaties in gevaar te brengen. Videolaryngoscopie wordt vaak gereserveerd voor voorspelde moeilijke intubaties.

In **Hoofdstuk 4** vroegen we 65 anesthesiologen, 67 anesthesiologen in opleiding, 56 ambulanceverpleegkundigen en 65 medische studenten de trachea van een gestandaardiseerd mannequin model met een normale luchtweg te intuberen met behulp van een klassieke Macintosh laryngoscoop en zeven VLS: Airtraq®, C-MAC®, Coopdech VLP-100®, C-MAC D-Blade®, GlideScope Cobalt®, McGrath Series 5® en Pentax AWS® in willekeurige volgorde. Doel van deze studie was het geven van een indicatie welke videolaryngoscoop het meest geschikt is voor welke zorgverlener. Voor de verschillende VLS die werden getest, bleek geen enkel apparaat de beste keuze voor alle gebruikers. Allen waren echter het snelst met VLS met een Macintosh-type blad, maar hadden aanzienlijk meer pogingen nodig wanneer ze de Airtraq en Pentax AWS gebruikten (alle $p < 0.05$). Apparaten met een Macintosh-type blad (klassieke laryngoscoop en C-MAC) scoorden het hoogste qua gebruikers tevredenheid. Uit dit hoofdstuk blijkt dat een balans tussen de voordelen van VLS en het eventuele nadeel van het moeten aanleren van nieuwe vaardigheden kan worden gevonden in een blad met de klassieke Macintosh vorm (bijvoorbeeld C-MAC en Coopdech VLS). Deze resultaten onderstrepen het belang van variabiliteit tussen apparaten, tussen individuen en tussen beroepsgroepen. Dit heeft belangrijke implicaties met betrekking tot welke apparaten rationeel het beste kunnen worden aangeschaft. De keuze voor een (video)laryngoscoop moet worden gemaakt op basis van de eisen die worden gesteld aan het apparaat en de persoon die het zal gaan gebruiken.

VLS maken tracheale intubatie mogelijk zonder uitgebreide ervaring. Een zeer goede visualisatie van de mondholte is een van de belangrijkste kenmerken van videolaryngoscopie. Hierbij is verlichting een belangrijk maar onderschat aspect dat visualisatie beïnvloedt. Duidelijke zichtbaarheid van de orofaryngeale en laryngeale structuren en voldoende ruimte in de mond om te manoeuvreren met een TT en andere attributen (bijv. gum elastic bougie, stylet, neus-maagsonde en Magill tang) zijn sleutels tot succes. Hoewel het ontbreken van optimale verlichting niet per sé hoeft te leiden tot een mislukte tracheale intubatie, blijft het risico op trauma bestaan.

In **Hoofdstuk 5** werd de intensiteit van verlichting van de mondholte door verschillende VLS vergeleken. Apparaten werden vergeleken in de donkere kamer van een fotograaf, in de operatiekamer en buiten bij direct zonlicht. De licht intensiteit werd gemeten bij de mondopening van een Laerdal® intubatietrainer. Lichtintensiteit verschilde aanzienlijk tussen apparaten en was het beste bij het gebruik van de C-MAC videolaryngoscoop. Als we onze resultaten vergelijken met de eerder gemaakte aanbevelingen voor DL (een minimaal vereiste lichtintensiteit van 100 cd/m2), was de verlichting slecht bij alle geteste VLS, behalve bij de C-MAC bij gebruik in de operatiekamer. Het is belangrijk dat men zich bewust is van deze mogelijke tekortkomingen en verschillen tussen apparaten.

Om dieper in te gaan op de voordelen van videolaryngoscopie hebben we in **Hoofdstuk 6** onderzocht of het gebruik van drie verschillende merken VLS, dat wil zeggen McGrath series 5, C-MAC en GlideScope Cobalt, resulteert in een afname van de kracht die wordt overgebracht op zowel de onder- als boventanden in vergelijking met een klassieke Macintosh laryngoscoop. Er is eerder aangetoond dat de krachten die op de boventanden van een patiënt worden uitgeoefend, minder zijn in vergelijking met een klassieke Macintosh laryngoscoop wanneer er gebruik wordt gemaakt van een videolaryngoscoop. Echter, eerdere studies evalueerden alleen één type videolaryngoscoop, of andere soorten dan die wij hebben onderzocht. Bovendien werden krachten op de ondertanden niet onderzocht.

Hoofdstuk 6 laat zien dat bij gebruik van videolaryngoscopie de krachten die op de boventanden worden uitgeoefend, minder zijn dan wanneer de klassieke Macintosh laryngoscoop wordt gebruikt. Er bestaan echter geen verschillen tussen de krachten die op de onderste tanden worden uitgeoefend. Het aantal contacten met de boventanden was het laagst bij de C-MAC, terwijl er geen verschillen waren in het aantal contacten tussen de andere VLS en de klassieke laryngoscoop. Ook de gemiddelde piekkrachten waren het laagst bij gebruik van de C-MAC. Op basis van dit resultaat wordt het sterk aanbevolen om videolaryngoscopie te gebruiken bij patiënten met een slecht gebit, kronen en/of bruggen. Bij de keuze van een bepaalde videolaryngoscoop voor deze categorie patiënten moet de anesthesioloog zich bewust zijn van verschillen tussen VLS met betrekking tot het risico op tandschade.



Naast de voordelen van videolaryngoscopie die in de vorige hoofdstukken werden behandeld, kan videolaryngoscopie nieuwe kansen op het gebied van luchtwegmanagement bieden. In **Hoofdstuk 7** presenteren we een nieuwe succesvolle intubatietechniek, waarbij een Macintosh-blad videolaryngoscoop wordt gecombineerd met een Bonfils®

intubatie endoscoop (BIE) voor een patiënt met een zeer moeilijke intubatie in de voorgeschiedenis. In **Hoofdstuk 8** hebben we deze techniek verder geëvalueerd. In totaal werden 38 patiënten, met een voorgeschiedenis van moeilijke intubatie of één of meer voorspellers van moeilijke intubatie, waarbij met behulp van een Macintosh-blad videolaryngoscoop een Cormack & Lehane (C&L) graad III of IV werd gescoord, geïncludeerd. Patiënten werden geïntubeerd door de videolaryngoscoop te combineren met de BIE. De C&L-score werd driemaal gescoord tijdens: a) DL; B) indirecte videolaryngoscopie; en c) gebruik van de gecombineerde techniek. Vervolgens beoordeelden twee anesthesiologen die geblindeerd waren voor de gebruikte intubatietechniek de C&L-graad aan de hand van de afbeeldingen die tijdens de procedure werden vastgelegd. Gebruik van de gecombineerde techniek vergemakkelijkte de intubatie en resulteerde in verbeterde laryngoscopie met een hoge mate van succes bij de eerste intubatiepoging en een succesvolle intubatie in de overgrote meerderheid van de gevallen. De gemiddelde tijd tot succesvolle intubatie bedroeg niet meer dan 30 seconden. Het betere zicht op de glottis, zoals gescoord door de intuberende anesthesioloog, werd in bijna alle gevallen bevestigd wanneer twee onafhankelijke en geblindeerde beoordelaars dit evalueerden.

De gecombineerde intubatietechniek biedt de anesthesioloog een alternatieve optie wanneer hij of zij geconfronteerd wordt met een moeilijke intubatie. Tegenwoordig zullen de meeste anesthesiologen vertrouwen op een videolaryngoscoop wanneer ze geconfronteerd worden met een moeilijke intubatie. Wanneer de patiënt al onder anesthesie is gebracht en gebruik van een videolaryngoscoop leidt tot een onverwachte C&L graad III of IV, blijven er maar een beperkt aantal opties over. Voordelen van de gecombineerde techniek zijn: 1) minder stress voor de patiënt in vergelijking met wakker fiberoptische intubatie (aangezien de patiënt onder anesthesie is); 2) de techniek biedt een alternatief wanneer andere methoden falen; en 3) het vermijden van het gebruik van verschillende hulpmiddelen voor meerdere pogingen, verlaagt het risico op complicaties. Deze resultaten geven aan dat het gecombineerde gebruik van Macintosh-blad videolaryngoscopie en de BIE een veelbelovende alternatieve techniek is voor succesvolle intubatie van patiënten met moeilijke luchtwegen.

In **Hoofdstuk 9.1** wijzen wij erop dat de conclusie "de maximale kracht op de basis van de tong tijdens laryngoscopie is minder bij gebruik van de GlideScope Cobalt in vergelijking met de directe Macintosh laryngoscoop", zoals gegeven door andere onderzoekers, overeenkomt met onze eerdere bevinding dat het gebruik van videolaryngoscopie resulteert in het uitoefenen van minder kracht op de boventanden in vergelijking met DL (Hoofdstuk 6). De conclusie van deze onderzoekers moet echter voorzichtig worden geïnterpreteerd, aangezien het blad van de geteste videolaryngoscoop is aangepast, wat mogelijk resulteert in hogere krachten dan in werkelijkheid. Bovendien, bij het vergelijken van de GlideScope videolaryngoscoop met de directe Macintosh laryngoscoop, is het belangrijk dat men zich realiseert dat twee apparaten worden vergeleken met volledig verschillende bladontwerpen.

In de Letter-to-the-Editor gepresenteerd in **Hoofdstuk 9.2** zijn we het niet eens met de stelling om in eerste instantie gebruik te maken van de Macintosh laryngoscoop bij patiënten met een lage luchtwegrisico score die intubatie met een dubbellumen TT nodig hebben en dus de McGrath videolaryngoscoop alleen te gebruiken bij patiënten met een hogere luchtwegrisico score. Wanneer een apparaat uitsluitend wordt gebruikt voor een moeilijke intubatie, kan de gebruiker er niet vertrouwd mee raken. Het belang van regelmatige en herhaaldelijke oefening moet niet onderschat worden.

In **Hoofdstuk 10,** de algemene discussie, wordt de positie van videolaryngoscopie ten opzichte van DL besproken, evenals het belang dat gebruikers zich bewust zijn van de noodzaak tot training met VLS, de verschillen tussen VLS en de mogelijke voordelen, nadelen en specifieke complicaties die het gevolg kunnen zijn van het gebruik van verschillende VLS. Verder in Hoofdstuk 10 richten we ons op de uitgebreide mogelijkheden van videolaryngoscopie en de implicaties ervan voor de toekomst.

Tenslotte wordt in **Hoofdstuk 11** een samenvatting gegeven in het Engels en het Nederlands om de belangrijkste bevindingen van dit proefschrift te benadrukken.

# Dankwoord

Een dankwoord, het hoofdstuk dat in elk proefschrift waarschijnlijk toch door de meeste mensen gelezen wordt… En het hoofdstuk waarvan ik bij voorbaat al weet dat het niet volledig zal zijn. Maar er zijn mensen die ik sowieso wil noemen en bedanken voor hun directe of indirecte bijdrage aan mijn proefschrift.

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In de aanloop naar dit proefschrift heb ik in verschillende ziekenhuizen gewerkt. Ik zal een voorzichtige poging wagen de mensen die ik hierbij ben tegengekomen te bedanken...

Het gaat al mis in Maastricht. Ik kan nooit iedereen bij naam noemen, maar in elk geval de anesthesiologen, arts-assistenten, intensivisten en zeker ook anesthesiemedewerkers en alle anderen die hebben bijgedragen aan een ontzettend leuke, gezellige maar ook degelijke opleidingstijd. Ik kan jullie eigenlijk niet genoeg bedanken.

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Terug in Nederland uit België was het even wennen, bedankt dat ik daar in Nijmegen de kans voor kreeg. Dank aan de anesthesiologen met een speciaal woord voor Luc (dank voor de onuitputtelijke didactische (echo)bron die je bent en je onofficiële mentorschap) en Andrea (het eten was heerlijk, en(!) gezellig :)). De arts-assistenten: bedankt voor het warme welkom. En zeker niet op de laatste plaats de anesthesiemedewerkers, ik vond het reuze gezellig en prettig met jullie samenwerken. Ook hier is een speciaal woord op z'n plaats; Michel: het was een eer en een genoegen met je samen te mogen werken; Astrid: datzelfde geldt voor jou.

En uiteraard mijn huidige collega's: anesthesiologen, anesthesiemedewerkers, aios, operatieassistenten en alle anderen. Na mijn omzwervingen langs verschillende ziekenhuizen voel ik me tussen jullie op mijn gemak en op mijn plek. Bedankt voor de kansen die ik krijg en de mogelijkheden die jullie bieden. Wat mij betreft op naar een mooie toekomst!

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Alexander & Jacqueline, onbeschrijfelijk hoe jullie er steeds waren, de afleiding, de bemoedigende woorden, dank voor de kleur tussen het donkerblauw, grijs en bruin.

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Lieve Erik, wat is het fijn met jou. Alles en zo.

# Curriculum vitae

Barbe Marie Anne Pieters was born on September 6th, 1983 in Heerlen, The Netherlands. In 2001 she graduated from the Augustinianum Scholengemeenschap in Eindhoven, The Netherlands.

In the same year, she moved to Maastricht, where she started her medical training at the Faculty of Medicine at the University of Maastricht. From August 2007, immediately after obtaining her medical doctor degree, she started working as a resident (anios) at the intensive care department of the MUMC+.

In december 2007, Barbe Pieters started her anaesthesia residency at the MUMC+ (Prof. Dr. M. van Kleef, Prof. Dr. M.A. Marcus). During the second year of her residency, at the Catharina Hospital Eindhoven, she became involved (alongside her residency) in the research programme set up by Prof. Dr. A.A.J. van Zundert investigating the merits of videolaryngoscopy. From 2010, she started working on her PhD under supervision of Prof. Dr. A.A.J. van Zundert.

After completing her anaesthesia residency at the MUMC+ in 2012, she moved to Utrecht to start her fellowship in intensive care medicine at the University Medical Centre Utrecht (Prof. Dr. J. Kesecioglu, Prof. Dr. D. van Dijk). Following completion of her fellowship, Barbe moved to Leuven, Belgium to start a fellowship in paediatric and adult cardiothoracic anaesthesia at the University Hospitals Leuven (Prof. Dr. M. van de Velde).

After her time in Belgium, she worked as a paediatric anaesthetist at the Radboud University Medical Centre, Nijmegen, The Netherlands. In 2016, she returned to the University Medical Centre Utrecht to work as a paediatric anaesthetist. At the same time Prof. Dr. J.T.A. Knape joined Prof. Dr. A.A.J. van Zundert in the supervision of her PhD project.

Barbe Pieters currently lives with her husband in Utrecht, The Netherlands.

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