Association of Overlapping Surgery With Perioperative Outcomes

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IMPORTANCE Overlapping surgery, in which more than 1 procedure performed by the same primary surgeon is scheduled so the start time of one procedure overlaps with the end time of another, is of concern because of potential adverse outcomes.

OBJECTIVE To determine the association between overlapping surgery and mortality, complications, and length of surgery.

DESIGN, SETTING, AND PARTICIPANTS Retrospective cohort study of 66 430 operations in patients aged 18 to 90 years undergoing total knee or hip arthroplasty; spine surgery; coronary artery bypass graft (CABG) surgery; and craniotomy at 8 centers between January 1, 2010, and May 31, 2018. Patients were followed up until discharge.

EXPOSURES Overlapping surgery (≥2 operations performed by the same surgeon in which ≥1 hour of 1 case, or the entire case for those <1 hour, occurs when another procedure is being performed).

MAIN OUTCOMES AND MEASURES Primary outcomes were in-hospital mortality or complications (major: thromboembolic event, pneumonia, sepsis, stroke, or myocardial infarction; minor: urinary tract or surgical site infection) and surgery duration.

RESULTS The final sample consisted of 66 430 operations (mean patient age, 59 [SD, 15] years; 31 915 women [48%]), of which 8224 (12%) were overlapping. After adjusting for confounders, overlapping surgery was not associated with a significant difference in in-hospital mortality (1.9% overlapping vs 1.6% nonoverlapping; difference, 0.3% [95% CI, −0.2% to 0.7%]; P = .21) or risk of complications (12.8% overlapping vs 11.8% nonoverlapping; difference, 0.9% [95% CI, −0.1% to 1.9%]; P = .08). Overlapping surgery was associated with increased surgery length (204 vs 173 minutes; difference, 30 minutes [95% CI, 24 to 37 minutes]; P < .001). Overlapping surgery was significantly associated with increased mortality and increased complications among patients having a high preoperative predicted risk for mortality and complications, compared with low-risk patients (mortality: 5.8% vs 4.7%; difference, 1.2% [95% CI, 0.1% to 2.2%]; P = .03; complications: 29.2% vs 27.0%; difference, 2.3% [95% CI, 0.3% to 4.3%]; P = .03).

CONCLUSIONS AND RELEVANCE Among adults undergoing common operations, overlapping surgery was not significantly associated with differences in in-hospital mortality or postoperative complication rates but was significantly associated with increased surgery length. Further research is needed to understand the association of overlapping surgery with these outcomes among specific patient subgroups.

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Overlapping surgery refers to a situation in which more than 1 procedure performed by the same primary surgeon is scheduled so the timing of the start of one procedure overlaps with the timing of the end of another procedure.[1] Typically, trainees or nonphysician clinicians perform the less complicated portions of a procedure, while the primary surgeon moves between cases to perform the critical portions of the operations. A related concept, concurrent surgery, refers to situations in which the critical parts of operations occur during the same time.[1-3] There is concern that overlapping surgery may be associated with adverse patient outcomes.[3-5] For example, surgeons may less effectively address complications because they are absent at a crucial time.

To date, most studies have found no association between overlapping surgery and patient outcomes.[6-15] Prior studies have limitations, however. These include analyzing outcomes at single institutions and focusing on narrow sets of procedures,[6,7,9,10,15] which limit statistical power and generalizability; not accounting for differences between surgeons who do and do not perform overlapping surgery,[6,7,9-12,15] which may bias findings toward the null if surgeons who perform overlapping procedures are more experienced or select lower-risk cases; examining an inaccurate measure of overlap by only considering operations recorded in procedure-specific registries, rather than all operations performed with overlap by the same surgeon, which would undercount overlapping cases[11,12]; and defining overlapping surgery as having any overlap, no matter how small (eg, 1 minute), which may bias analyses toward finding no relationship between overlapping surgery and patient outcomes (ie, a bias toward a null funding if cases with very small overlap are unlikely to be associated with poorer outcomes).[13]

Using a multicenter registry of operations, this study examined associations between overlapping surgery and in-hospital mortality, in-hospital postoperative complications, and length of surgery. The registry contained comprehensive information for all operations performed by a given surgeon, allowing comparisons between outcomes for overlapping and nonoverlapping operations of the same type.

Methods

Data

The Multicenter Perioperative Outcomes Group (MPOG [http://mpog.org]) is an electronic health record registry of all surgical and diagnostic procedures requiring anesthesia care from more than 50 hospitals across 18 states and 2 countries (the United States and the Netherlands). The registry has received approval from the institutional review board at the University of Michigan and contributing centers, and analysis of the data set for this study was deemed exempt from human subjects review and requirement of consent.

For each case, MPOG contains information on surgical start and stop times (corresponding to incision and completion of surgical closure), an encrypted attending surgeon identifier, in-hospital mortality, a text descriptor of the surgery, and *International Classification of Diseases, Ninth Revision/ International Statistical Classification of Diseases and Related*

Key Points

Question Is overlapping surgery, in which a primary surgeon is involved in more than 1 case simultaneously, associated with worse perioperative outcomes compared with nonoverlapping surgery?

Findings In this retrospective cohort study of 66 430 adults undergoing common operations, overlapping surgery was not significantly associated with differences in in-hospital mortality (adjusted rate, 1.9% vs 1.6%) or postoperative complications (adjusted rate, 12.8% vs 11.8%) but was significantly associated with increased surgery length (adjusted length, 204 vs 173 minutes).

Meaning Overlapping surgery was not significantly associated with differences in in-hospital mortality or postoperative complication rates but was significantly associated with increased surgery length. Further research is needed to understand the association of overlapping surgery with these outcomes among specific patient subgroups.

Health Problems, Tenth Revision diagnosis codes from the discharge abstract, allowing for risk adjustment and outcome measurement. Extensive steps are taken to ensure the accuracy of the data submitted to MPOG. For example, data must satisfy an array of quality diagnostics before the data can be used by researchers, and every month a sample of cases (≈20) submitted to MPOG from a given institution is reviewed by a clinician or data abstractor located at the submitting institution. The data are available to researchers after submission and approval of a draft research proposal. MPOG data have been used in several perioperative outcome studies.[16-22]

Sample

The study used a sample of patients aged 18 to 90 years who underwent 1 of 7 procedures between January 1, 2010, and May 31, 2018: total knee or hip arthroplasty; lumbar, thoracic, or cervical spine surgery; coronary artery bypass graft (CABG) surgery; or craniotomy. These procedures were chosen because they are commonly performed and the incidence of overlapping surgery is thought to be particularly high for these operations (see eAppendix 1 in the Supplement for description of how operations were identified). Patients could be included in the sample more than once if they underwent multiple operations during this period. Because many MPOG institutions do not consistently report discharge diagnosis codes, the analysis was restricted to 8 US institutions that consistently did so (defined as having codes present for >70% of cases) and that also reported mortality data.

The following exclusion criteria were also applied. Observations with missing data on discharge, mortality, surgery duration, or patient sex were excluded. Cases in which the American Society of Anesthesiologists Physical Status (ASAPS) classification system score was missing or equal to 6 (signifying an organ harvest patient) and cases composed of more than 1 surgery type were also excluded. Last, because the statistical approach relied on exposure of patients to overlapping or nonoverlapping operations performed by the same surgeon, surgeon-procedure combinations with fewer than 20 observations were excluded.

Exposure

A given case was defined as overlapping with other cases if the surgery start and end time overlapped with at least 1 other operation (of any type) performed by the same surgeon for at least 60 minutes. For cases less than 60 minutes in surgical duration (ie, difference between surgery end and start times <60 minutes), overlap was defined as having a start and end time that overlapped for the entirety of the other case.[11,12] Thus, the control group consisted of cases with no overlap as well as cases lasting longer than 60 minutes that had overlap of less than 59 minutes with another case. In constructing the overlap measure, the analysis included overlap with any case present in the data, not simply those cases meeting the inclusion and exclusion criteria.

Outcomes

The primary outcomes were in-hospital mortality, the occurrence of an in-hospital postoperative surgical complication, and duration of the surgery. In-hospital mortality was obtained from data provided to MPOG by the member institution. Postoperative complications were defined as the occurrence of any of the following during the hospitalization, based on the presence of discharge diagnosis codes[23-25]: surgical site infection or urinary tract infection (which were categorized as minor complications) and pneumonia, sepsis, thromboembolic event (deep venous thrombosis or pulmonary embolism), stroke, or myocardial infarction (which were classified as major complications). Specific diagnosis codes are provided in eTable 1 in the Supplement.

Additional Variables

Several additional variables, which are directly reported to MPOG, were included to adjust for potential confounders: patient age and sex, year of surgery, day of surgery, hour of surgery, and ASAPS score. The ASAPS is a score reported by the attending anesthesiologist that serves as a summary measure of the patient's health status. Organ donors (excluded from the study) receive a score of 6. Otherwise, the score ranges from 1 (healthy patient) to 5 (moribund patient unlikely to survive without surgery), with the letter "E" used to identify procedures for an emergent indication (eg, "1E" indicates a healthy patient undergoing emergency surgery). In addition, discharge diagnosis codes reported to MPOG were used to identify the presence of comorbidities included in the Elixhauser Index (**Table 1**).[26]

Statistical Analyses

Comparisons of outcomes between overlapping and nonoverlapping cases may also be confounded by unobserved differences across surgeons in technique, skill, experience, and patient populations. For example, surgeons who perform overlapping procedures may be more experienced than those who do not, or they may preferentially choose to center their practice on lower-risk cases that would be more appropriate for overlapping surgery. To address this, multivariable models were estimated that included surgeon-procedure fixed effects. This approach estimated the association between overlapping scheduling and outcomes by comparing outcomes of a given surgeon's overlapping and nonoverlapping operations of the same type. For example, the study would com-

pare outcomes between a given surgeon's hip replacements performed with overlap against the same surgeon's hip replacements performed without overlap.

For each outcome, multivariable linear regressions were estimated in which the independent variable of interest was whether the case met the definition of overlap. Additional covariates included surgeon-procedure fixed effects (the surgeon-procedure pair) and the patient and surgery characteristics described above. Although in-hospital mortality and postoperative complications were binary outcomes, the study estimated linear probability models rather than logistic models for 2 reasons.[27-29] First, because of the large number of fixed effects (1 for each surgeon-procedure pair), the maximum likelihood algorithm for logistic regression failed to converge.[30] Second, fixed effects in nonlinear models can lead to biased estimates.[31]

All analyses were performed using standard commands (ie, *reg* and *areg*) in Stata version 14.0 (StataCorp), and 2-sided *P* values were used to assess statistical significance, with a threshold of .05 or less.

Subgroup Analyses

Two prespecified exploratory subgroup analyses were performed. First, statistical models in which the overlap variable (as well as all other variables in the regression model) was interacted with type of surgery were estimated to examine whether the association between overlap and outcomes differed across surgery type. Second, the study separately analyzed patients at high predicted risk for in-hospital mortality and complications, hypothesizing that surgical overlap may be associated with larger differences for these patients. A multivariable logistic regression was used to estimate the predicted probability of in-hospital death or in-hospital postoperative complications on the basis of age, sex, ASAPS score, and the comorbidities listed in Table 1. High-risk patients were then defined as those in the top quartile in terms of predicted probability for either in-hospital death or postoperative complication (eAppendix 2 in the Supplement).

Sensitivity Analyses

The main statistical model reduced confounding by (1) adjusting for observable factors (eg, patient comorbidities) that could be associated with outcomes and (2) comparing outcomes for a given surgeon's overlapping and nonoverlapping cases of the same surgery type, as opposed to comparing outcomes across surgeons, hospitals, or procedure types, assuming that patients undergoing the same type of surgery from the same surgeon, eg, hip replacement, have similar characteristics. However, this approach could be confounded if this assumption did not hold, for example, if surgeons preferentially choose to schedule lower-risk or less complex cases with overlap. This issue was addressed through several post hoc sensitivity analyses.

First, regression analysis was used to examine whether the distribution of observable patient characteristics was different between overlapping and nonoverlapping cases within surgeon-procedure pairs (eAppendix 3 in the Supplement), with the reasoning that similarity in a large set of observable patient factors between overlapping and nonoverlapping cases (within surgeon-procedure pairs) could suggest, although not definitely

Table 1. Patient Characteristics

Characteristic	Overlapping Surgery (n = 8224)	Nonoverlapping Surgery (n = 58 206)	Difference (95% CI)	
			Unadjusted	Adjusted[a]
Patient demographics				
Age, mean (SD), y	56.4 (15.2)	59.2 (14.8)	−2.7 (−4.7 to −0.7)	0.2 (−0.4 to 0.7)
Sex, No. (%)				
Men	4356 (53.0)	30 159 (51.8)	1.1 (−2.9 to 5.2)	0.6 (−0.7 to 1.9)
Women	3868 (47.0)	28 047 (48.2)	−1.1 (−5.2 to 2.9)	−0.6 (−1.9 to 0.7)
ASAPS score[b]				
Numerical score, mean (SD)	2.7 (0.7)	2.6 (0.8)	0.1 (0.0 to 0.2)	0.02 (−0.01 to 0.05)
Emergency status, No. (%)	446 (5.4)	4078 (7.0)	−1.6 (−3.0 to −0.1)	−1.4 (−3.0 to 0.2)
Patient comorbidities, No. (%)				
Hypertension, without complications	549 (46.4)	28 264 (48.6)	−2.1 (−4.6 to 0.4)	1.6 (0.0 to 3.1)
Obesity	1130 (13.7)	11 094 (19.1)	−5.3 (−9.6 to −1.6)	1.8 (−0.6 to 3.0)
Dysrhythmia	1213 (14.7)	9364 (16.1)	−1.3 (−4.5 to 1.9)	−0.5 (−1.7 to 0.7)
Depression	1277 (15.5)	9936 (16.1)	−0.6 (−2.1 to 0.9)	−0.1 (−1.2 to 0.9)
COPD	1256 (15.3)	9100 (15.6)	−0.3 (−1.8 to 1.1)	−0.1 (−1.1 to 0.8)
Fluid/electrolyte disorder	1689 (20.5)	9035 (15.5)	5.0 (0.2 to 9.8)	0.4 (−0.7 to 1.6)
Diabetes, without complications	851 (10.3)	7186 (12.3)	−2.0 (−4.2 to 0.2)	0.4 (−0.5 to 1.4)
Hypothyroidism	884 (10.7)	6869 (11.8)	−1.1 (−2.0 to 0.0)	0.0 (−1.0 to 0.9)
Neurologic disorders	1341 (16.3)	6588 (11.3)	5.0 (0.0 to 10.0)	0.7 (−0.1 to 1.6)
Solid tumor	1159 (14.1)	5936 (10.2)	3.9 (−2.2 to 10.0)	0.9 (0.0 to 1.8)
Renal failure	569 (7.0)	4630 (8.0)	−1.0 (−3.0 to 0.9)	0.1 (−0.5 to 0.7)
Congestive heart failure	605 (7.4)	4539 (7.8)	−0.4 (−3.0 to 2.0)	0.0 (−0.6 to 0.7)
Hypertension, with complications	3820 (6.7)	4487 (7.7)	−1.0 (−2.9 to 0.9)	0.0 (−0.7 to 0.5)
Valvular disease	544 (6.6)	4177 (7.2)	−0.6 (−3.4 to 2.3)	−0.5 (−1.2 to 1.6)
Peripheral vascular disease	709 (8.6)	3733 (6.4)	2.2 (−1.0 to 5.5)	0.0 (−0.9 to 0.8)
Metastatic cancer	491 (6.0)	3477 (6.0)	0.0 (−2.3 to 2.3)	−0.3 (−1.2 to 0.6)
Coagulopathy	474 (5.8)	3361 (5.8)	0.0 (−1.6 to 1.6)	−0.7 (−1.5 to 0.1)
Paralysis	495 (6.0)	2673 (4.6)	1.4 (−0.1 to 3.0)	0.0 (−0.7 to 0.6)
Rheumatoid arthritis	247 (3.0)	2345 (4.0)	−1.0 (−1.8 to −0.3)	0.0 (−0.4 to 0.4)
Pulmonary circulation disorder	314 (3.8)	1948 (3.3)	0.5 (−0.5 to 1.4)	0.4 (−0.2 to 0.9)
Weight loss	318 (3.9)	1943 (3.3)	0.6 (−0.3 to 1.3)	0.5 (−0.1 to 1.0)
Liver disease	223 (2.7)	1760 (3.0)	−0.3 (−0.9 to 0.3)	0.1 (−0.2 to 0.5)
Drug abuse	308 (3.7)	1671 (2.9)	0.8 (−0.2 to 1.9)	0.1 (−0.5 to 0.6)
Diabetes, with complications	146 (1.8)	1668 (2.9)	−1.0 (−1.8 to −0.4)	0.0 (−0.4 to 0.2)
Iron-deficiency anemia	120 (1.5)	1093 (1.9)	−0.4 (−0.8 to −0.1)	0.3 (−0.1 to 0.6)
Alcohol abuse	182 (2.2)	1000 (1.7)	0.5 (0.2 to 0.8)	0.3 (0.0 to 0.7)
Lymphoma	78 (0.9)	605 (1.0)	−0.1 (−0.3 to 0.2)	0.0 (−0.2 to 0.3)
Psychosis	107 (1.3)	574 (1.0)	0.3 (0.0 to 0.6)	0.0 (−0.2 to 0.3)
Peptic ulcer disease	44 (0.5)	352 (0.6)	−0.1 (−0.3 to 0.1)	0.1 (−0.1 to 0.3)
Blood loss anemia	33 (0.4)	339 (0.6)	−0.2 (−0.4 to 0.0)	0.0 (−0.2 to 0.1)
AIDS/HIV	20 (0.2)	84 (0.1)	0.1 (−0.0 to 0.2)	0.1 (−0.0 to 0.3)
Predicted mortality or complication risk, No. (%)[c]				
Low risk	5212 (63.4)	40 361 (69.3)	−6.0 (−4.9 to 7.0)	0.0 (−1.8 to 1.8)
High risk	3012 (36.6)	17 845 (30.7)	6.0 (4.9 to 7.0)	0.0 (−1.8 to 1.8)

Abbreviations: ASAPS, American Society of Anesthesiologists Physical Status; COPD, chronic obstructive pulmonary disease.

[a] Adjusted differences refer to differences between overlapping and nonoverlapping operations after using regression analyses to adjust for surgeon-procedure pair, date of surgery, and time of surgery. Confidence intervals adjusted for clustering at the surgeon level.

[b] Consists of a numerical score and an indicator "E" for emergency surgery. The numerical score ranges from 1 to 6, with 1 signifying a healthy patient, 3 a patient with severe systemic disease, 5 a moribund patient not expected to survive without the operation, and 6 an organ harvest patient.
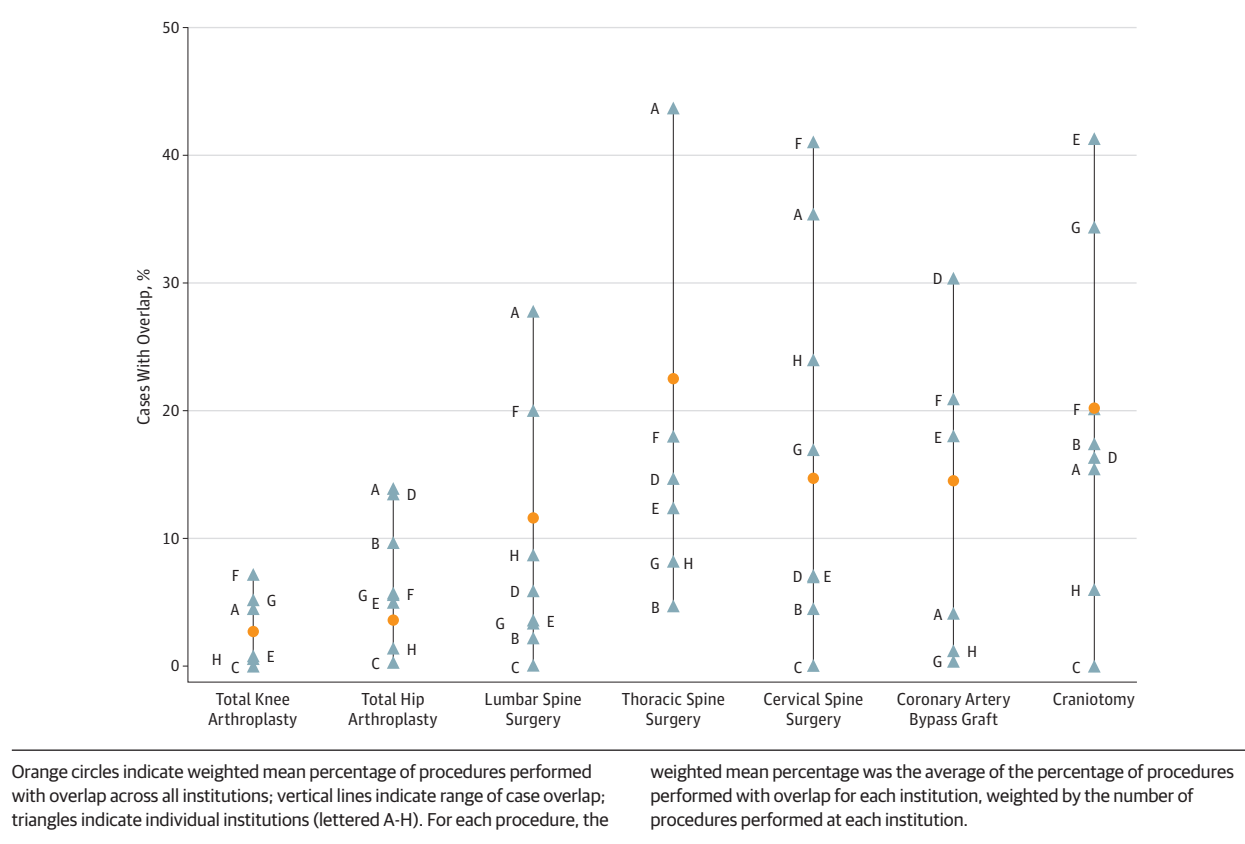
[c] High risk refers to patients predicted to be in the upper quartile of risk for mortality or complications on the basis of the remaining characteristics shown in Table 1 and the methods described in the text; low risk refers to patients not at high risk.

state, that unobservable patient factors were also similar between groups. Second, a possible source of confounding is that high-risk, unscheduled or emergent cases may be more likely to involve overlap, since the surgeon may be required to operate immediately, even if he or she is performing another procedure. Subanalyses were therefore performed for cases that were likely to be elective, by excluding operations that were (1)

designated as emergency by the anesthesiologist, (2) performed on the weekend, or (3) started between 4 PM and 7 AM. Third, a multiple imputation analysis was performed to assess the sensitivity of results to missing data.

In addition, the robustness of the main results to alternative definitions of overlap was examined. First, in the baseline model, the control group implicitly included cases with no

Figure. Percentage of Surgical Cases With Overlap at Each Institution, by Surgery Type

Orange circles indicate weighted mean percentage of procedures performed with overlap across all institutions; vertical lines indicate range of case overlap; triangles indicate individual institutions (lettered A-H). For each procedure, the weighted mean percentage was the average of the percentage of procedures performed with overlap for each institution, weighted by the number of procedures performed at each institution.

overlap as well as cases with minimal overlap (less than 59 minutes for cases longer than 60 minutes); a separate analysis excluded cases with overlap of less than 59 minutes (for cases longer than 60 minutes) from the control group. Second, additional analyses were performed in which overlapping cases were defined as those having any overlap (eg, at least 1 minute) with other procedures performed by the same surgeon.[13]

Alternative outcome definitions were also considered. Specifically, in post hoc analysis, complications were divided into 2 groups: minor (urinary tract and surgical site infection) and major (thromboembolic event, pneumonia, sepsis, stroke, or myocardial infarction). Associations of overlapping surgery with all major complications, all minor complications, and each specific complication were analyzed. In addition, in the case of CABG surgery, a separate analysis was conducted that adjusted for higher-risk procedures (repeat procedure or CABG surgery plus a valve procedure).

Results

Patient Characteristics

From an initial sample of 87 560 cases, cases were excluded for the following reasons: missing data on discharge (n = 7023), mortality (n = 1070), surgery duration (n = 4728), or patient sex (n = 30); ASAPS score missing or equal to 6 (n = 1994); cases composed of more than 1 surgery type (n = 4167); and surgeon-

procedure combinations with fewer than 20 observations (n = 2118). The final sample consisted of 66 430 procedures performed by 207 surgeons with 373 surgeon-procedure pairs. Cases excluded for missing data were qualitatively similar to the final sample in many dimensions (ie, patient age, patient sex, ASAPS score) (eTable 2 in the Supplement).

In the final sample of cases, 31 915 (48%) occurred in women and 8224 (12%) were overlapping. The mean patient age was 59 years (SD, 15 years). The sample included 15 832 craniotomies (24%), 15 905 lumbar spine procedures (24%), 9437 total hip arthroplasties (14%), 8567 cervical spine procedures (13%), 8282 total knee arthroplasties (12%), 6539 CABG procedures (10%), and 1868 thoracic spine procedures (3%).

The mean number of cases per surgeon was 320, with a median of 199 (interquartile range [IQR], 77-495). Of the 207 surgeons in the analytic sample, 151 (73%) performed overlapping procedures. Among surgeons who performed overlapping procedures, the mean percentage of a surgeon's cases that were overlapping was 12% (median, 6% [IQR, 2%-15%]). Overlapping scheduling was most common for craniotomy (17% performed with overlap at the median institution; ie, at half of institutions, ≤17% of craniotomies were overlapping [IQR, 11%-27%]) and least common for total knee arthroplasty (median, 2% [IQR, 1%-5%]) (Figure).

Unadjusted patient characteristics were generally similar between overlapping and nonoverlapping cases. Exceptions were age, emergent case status, obesity, hypothyroidism, rheumatoid

Table 2. Association Between Overlapping Surgery and In-Hospital Mortality

	In-Hospital Complications, % (95% CI)							
	Unadjusted				Adjusted[a]			
	Overlapping	Nonoverlapping	Difference	P Value[b]	Overlapping	Nonoverlapping	Difference	P Value[b]
Primary Analysis								
All operations combined (N = 66 430)	2.1 (1.5 to 2.6)	1.6 (1.2 to 2.0)	0.4 (−0.1 to 9.9)	.11	1.9 (1.5 to 2.3)	1.6 (1.6 to 1.7)	0.3 (−0.2 to 0.7)	.21
Exploratory Subgroup Analyses								
Surgery								
Total knee arthroplasty (n = 8282)	0.0 (0.0 to 0.0)	0.02 (0.0 to 0.06)	−0.02 (−0.06 to 0.01)	.14	0.01 (−0.03 to 0.05)	0.02 (0.02 to 0.03)	−0.02 (−0.06 to 0.02)	.37
Total hip arthroplasty (n = 9437)	0.6 (0.0 to 1.5)	0.2 (0.1 to 0.3)	0.4 (−0.4 to 1.3)	.38	0.3 (−0.4 to 1.1)	0.2 (0.2 to 0.2)	0.1 (−0.6 to 0.8)	.80
Lumbar spine (n = 15 905)	0.3 (0.0 to 0.6)	0.3 (0.1 to 0.4)	0.04 (−0.2 to 0.3)	.76	0.4 (0.1 to 0.8)	0.3 (0.2 to 0.3)	0.1 (−0.2 to 0.5)	.45
Thoracic spine (n = 1868)	1.0 (0.3 to 1.6)	2.5 (1.6 to 3.4)	−1.5 (−2.8 to −0.2)	.02	1.6 (0.1 to 3.0)	2.3 (1.9 to 2.7)	−0.7 (−2.6 to 1.2)	.44
Cervical spine (n = 8567)	1.0 (0.4 to 1.5)	1.2 (0.8 to 1.7)	−0.3 (−0.9 to 0.4)	.41	1.1 (0.6 to 1.5)	1.2 (1.1 to 1.3)	−0.1 (−0.7 to 0.4)	.60
CABG surgery (n = 6539)	3.7 (2.1 to 5.2)	2.2 (1.6 to 2.8)	1.5 (0.0 to 3.1)	.06	4.0 (2.8 to 5.1)	2.2 (2.0 to 2.4)	1.8 (0.5 to 3.2)	.009
Craniotomy (n = 15 832)	3.4 (2.3 to 4.6)	5.0 (4.0 to 6.0)	−1.5 (−2.6 to −0.4)	.007	5.0 (4.4 to 5.7)	4.6 (4.4 to 4.7)	0.5 (−0.4 to 1.3)	.27
Predicted mortality or complication risk[c]								
Low risk (n = 45 573)	0.3 (0.1 to 0.4)	0.2 (0.1 to 0.3)	0.1 (0.0 to 0.2)	.18	0.1 (0.0 to 0.2)	0.2 (0.2 to 0.3)	−0.1 (−0.2 to 0.0)	.07
High risk (n = 20 857)	5.1 (4.0 to 6.3)	4.8 (4.0 to 5.6)	0.3 (−0.8 to 1.5)	.15	5.8 (4.9 to 6.7)	4.7 (4.5 to 4.8)	1.2 (0.1 to 2.2)	.03

Abbreviation: CABG, coronary artery bypass graft.

[a] Adjusted refers to analyses that compare a given surgeon's overlapping vs nonoverlapping cases of the same procedure type and that also adjust for the patient characteristics shown in Table 1.

[b] Confidence intervals were adjusted for clustering at the surgeon level. The P values shown indicate whether the difference between the overlapping and nonoverlapping groups is significantly different from zero.

[c] High risk refers to 20 857 patients predicted to be at high risk for in-hospital

mortality or postoperative complications on the basis of the characteristics shown in Table 1 and methods described in the text; low risk refers to patients not at high risk. A test of interactions showed no significant differences in the relationship between overlapping surgery and mortality (P = .08 for F test) across surgery types. A test of interactions showed that surgical overlap was significantly associated with increased mortality between high-risk vs low-risk patients (P = .04 for test of interactions).

arthritis, diabetes with complications, and iron-deficiency anemia, which were significantly lower among overlapping cases; and fluid and electrolyte disorders and alcohol abuse, which were significantly higher among overlapping cases (Table 1). Differences in patient characteristics were smaller and not statistically significant when adjusted for surgeon-procedure fixed effects, an analysis conducted to complement the statistical design, which compared outcomes of overlapping vs nonoverlapping procedures of the same type performed by the same surgeon (Table 1; eTable 3 in the Supplement).

Main Analysis

The unadjusted mortality rate was 2.1% among overlapping procedures, compared with 1.6% for nonoverlapping (difference, 0.4% [95% CI, −0.1% to 9.9%]; P = .11) (Table 2). The unadjusted complication rate was 14.0% for overlapping cases, compared with 11.7% for nonoverlapping cases (difference, 2.3% [95% CI, −0.5% to 5.0%]; P = .10) (Table 3), while the unadjusted mean surgery length was 237 minutes for overlapping cases and 169 minutes for nonoverlapping cases (difference, 68 minutes [95% CI, 49 to 87 minutes]; P < .001) (Table 4).

After adjusting for surgeon-procedure fixed effects and patient characteristics (see eTable 4 in the Supplement for full regression results), there was no significant difference be-

tween overlapping vs nonoverlapping surgery for in-hospital mortality (1.9% for overlapping vs 1.6% for nonoverlapping; difference, 0.3% [95% CI, −0.2% to 0.7%]; P = .21) (Table 2) or postoperative complications (12.8% for overlapping vs 11.8% for nonoverlapping; difference, 0.9% [95% CI, −0.1% to 1.9%]; P = .08) (Table 3). Overlapping surgery was significantly associated with increased surgery length (204 vs 173 minutes; difference, 30 minutes [95% CI, 24 to 37 minutes]; P < .001) (Table 4).

Exploratory Subgroup Analyses

In prespecified, exploratory subgroup analyses, surgical overlap vs no surgical overlap during CABG surgery was associated with in-hospital mortality rates of 4.0% vs 2.2% (difference, 1.8% [95% CI, 0.5% to 3.2%]; P = .009) and complication rates of 34.5% vs 30.2% (difference, 4.3% [95% CI, 1.3% to 7.4%]; P = .007). However, a test of interactions showed no significant differences in the relationship between overlapping surgery and mortality (P = .08 for F test) or complications (P = .09 for F test) across surgery types. Surgical overlap among high-risk patients was significantly associated with increased mortality (5.8% vs 4.7%; difference, 1.2% [95% CI, 0.1% to 2.2%]; P = .03; P = .04 for difference compared with low-risk patients in a test of interactions) and complication rates

Table 3. Association Between Overlapping Surgery and In-Hospital Postoperative Complications

| | In-Hospital Complications, % (95% CI) | | | | | | | |
| | Unadjusted | | | | Adjusted[a] | | | |
	Overlapping	Nonoverlapping	Difference	P Value[b]	Overlapping	Nonoverlapping	Difference	P Value[b]
Primary Analysis								
All operations combined (N = 66 430)	14.0 (10.8 to 17.0)	11.7 (10.1 to 13.3)	2.3 (−0.5 to 5.0)	.10	12.8 (11.9 to 13.7)	11.8 (11.7 to 12.0)	0.9 (−0.1 to 1.9)	.08
Exploratory Subgroup Analyses								
Surgery								
Total knee arthroplasty (n = 8282)	4.4 (2.0 to 6.8)	4.9 (3.0 to 6.9)	−0.5 (−3.4 to 2.4)	.77	5.2 (3.2 to 7.2)	4.9 (4.8 to 5.0)	0.3 (−1.8 to 2.3)	.79
Total hip arthroplasty (n = 9437)	7.0 (3.8 to 10.3)	6.0 (3.9 to 8.1)	1.0 (−2.1 to 4.3)	.69	5.5 (2.4 to 8.6)	6.1 (5.9 to 6.2)	−0.6 (−3.8 to 2.7)	.72
Lumbar spine (n = 15 905)	6.8 (3.4 to 10.2)	6.2 (5.0 to 7.4)	0.6 (−2.4 to 3.6)	.80	5.9 (4.9 to 6.8)	6.4 (6.2 to 6.5)	−0.5 (−1.5 to 0.6)	.37
Thoracic spine (n = 1868)	16.6 (14.3 to 18.9)	21.4 (17.9 to 24.9)	−4.8 (−8.4 to −1.2)	.05	20.9 (17.0 to 24.8)	20.2 (19.0 to 21.3)	0.7 (−4.3 to 5.7)	.78
Cervical spine (n = 8567)	9.9 (5.8 to 14.1)	9.8 (8.2 to 11.5)	0.1 (−3.4 to 3.6)	.99	10.8 (8.9 to 12.7)	9.7 (9.4 to 10.0)	1.1 (−1.1 to 3.2)	.33
CABG surgery (n = 6539)	29.2 (24.0 to 34.4)	31.1 (27.9 to 34.2)	−1.8 (−7.2 to 3.4)	.49	34.5 (31.9 to 37.1)	30.2 (29.8 to 30.6)	4.3 (1.3 to 7.4)	.007
Craniotomy (n = 15 832)	16.2 (11.8 to 20.5)	17.5 (15.0 to 20.0)	−1.3 (−5.1 to 2.4)	.44	18.1 (16.7 to 19.5)	17.0 (16.6 to 17.3)	1.1 (−0.6 to 2.9)	.21
Predicted mortality or complication risk[c]								
Low risk (n = 45 573)	5.9 (4.3 to 7.6)	4.8 (4.0 to 5.6)	1.1 (−0.4 to 2.6)	.15	5.1 (4.2 to 5.9)	4.9 (4.8 to 5.0)	0.1 (−0.8 to 1.1)	.78
High risk (n = 20 857)	27.8 (24.5 to 31.1)	27.2 (25.3 to 29.1)	0.6 (−2.3 to 3.5)	.67	29.2 (27.5 to 30.9)	27.0 (26.7 to 27.2)	2.3 (0.3 to 4.3)	.03

Abbreviation: CABG, coronary artery bypass graft.

[a] Adjusted refers to analyses that compare a given surgeon's overlapping vs nonoverlapping cases of the same procedure type and that also adjust for the patient characteristics shown in Table 1.

[b] Confidence intervals were adjusted for clustering at the surgeon level. The P values shown indicate whether the difference between the overlapping and nonoverlapping groups is significantly different from zero.

[c] High risk refers to 20 857 patients predicted to be at high risk for in-hospital

mortality or postoperative complications on the basis of the characteristics shown in Table 1 and methods described in the text; low risk refers to patients not at high risk. A test of interactions showed no significant differences in the relationship between overlapping surgery and complications (P = .09 for F test) across surgery types. A test of interactions showed that surgical overlap was significantly associated with increased complications between high-risk vs low-risk patients (P = .04 for test of interactions).

(29.2% vs 27.0%; difference, 2.3% [95% CI, 0.3% to 4.3%]; P = .03; P = .04 for difference compared with low-risk patients in a test of interactions). Overlapping surgery was significantly associated with increased surgery length for all subgroups examined (Table 4).

Post Hoc Sensitivity Analyses
In further analyses to estimate the potential for confounding, overlapping and nonoverlapping cases were similar with respect to patient age, patient sex, and most patient comorbidities, after using regression analyses to adjust for surgeon-procedure pair, date of surgery, and time of surgery (Table 1; eTable 3 in the Supplement). Analyses confined to operations that were highly likely to be scheduled as elective cases produced results similar to the main findings (eTable 5 in the Supplement), as did analyses that directly compared cases meeting the definition of overlap (≥60 minutes for cases longer than 60 minutes, or the entirety of the case for shorter cases) against cases with absolutely no overlap (eTable 5 in the Supplement). Using a broader definition of overlap—having at least 1 minute of overlap with other procedures performed by the same surgeon—produced qualitatively similar results, although the estimated differences were smaller in magnitude (eTable 5 in the Supplement).

In analyses that separately considered each complication, overlapping surgery was significantly associated with an increased risk of major complications (10.7% vs 9.5%; difference, 1.2% [95% CI, 0.2% to 2.1%]; P = .02) (eTable 6 in the Supplement). Analyses that separately adjusted for high-risk CABG procedures produced similar results (eTable 7 in the Supplement). An analysis using multiple imputation to adjust for missing data produced results similar to the main findings (eTable 8 in the Supplement).

Discussion
In this retrospective analysis of 66 430 adults aged 18 to 90 years undergoing a diverse set of common surgical procedures at 8 high-volume medical centers, overlapping surgery was not associated with increased in-hospital mortality or overall complication rates but was significantly associated with an increased risk of complications and mortality for some patient subgroups and for surgery duration. A unique aspect of the study was that the data included all of a surgeon's cases during the study period, allowing for an analytic design that helped to minimize confounding by comparing a given surgeon's overlapping and nonoverlapping cases of the same type.

Table 4. Association Between Overlapping Surgery and Surgery Length

| | In-Hospital Complications, min (95% CI) | | | | | | | |
| | Unadjusted | | | | Adjusted[a] | | | |
	Overlapping	Nonoverlapping	Difference	P Value[b]	Overlapping	Nonoverlapping	Difference	P Value[b]
Primary Analysis								
All operations combined (N = 66 430)	237 (219 to 256)	169 (156 to 182)	68 (49 to 87)	<.001	204 (199 to 209)	173 (173 to 175)	30 (24 to 37)	<.001
Exploratory Subgroup Analyses								
Surgery								
Total knee arthroplasty (n = 8282)	126 (115 to 136)	104 (98 to 110)	22 (11 to 32)	<.001	122 (114 to 131)	104 (103 to 104)	18 (9 to 27)	<.001
Total hip arthroplasty (n = 9437)	157 (130 to 184)	105 (95 to 114)	52 (26 to 77)	<.001	127 (121 to 133)	106 (106 to 106)	21 (15 to 28)	<.001
Lumbar spine (n = 15 905)	209 (180 to 238)	159 (146 to 173)	49 (23 to 75)	<.001	191 (181 to 201)	162 (160 to 163)	30 (18 to 41)	<.001
Thoracic spine (n = 1868)	279 (246 to 311)	216 (198 to 232)	63 (32 to 94)	<.001	263 (248 to 278)	220 (215 to 224)	43 (24 to 61)	<.001
Cervical spine (n = 8567)	196 (179 to 214)	153 (143 to 163)	44 (24 to 62)	<.001	178 (165 to 190)	156 (153 to 158)	22 (7 to 36)	.003
CABG surgery (n = 6539)	278 (260 to 295)	294 (275 to 313)	−16 (−33 to 0.8)	.06	304 (299 to 309)	290 (289 to 290)	14 (9 to 20)	<.001
Craniotomy (n = 15 832)	269 (242 to 295)	216 (195 to 237)	53 (28 to 77)	<.001	254 (245 to 262)	220 (217 to 222)	34 (23 to 45)	<.001
Predicted mortality or complication risk[c]								
Low risk (n = 45 573)	223 (204 to 243)	149 (137 to 162)	74 (54 to 94)	<.001	183 (176 to 190)	155 (154 to 156)	28 (20 to 35)	<.001
High risk (n = 20 857)	261 (244 to 279)	213 (198 to 227)	48 (31 to 67)	<.001	247 (241 to 253)	215 (214 to 216)	32 (25 to 39)	<.001

Abbreviation: CABG, coronary artery bypass graft.

[a] Adjusted refers to analyses that compare a given surgeon's overlapping vs nonoverlapping cases of the same procedure type and that also adjust for the patient characteristics shown in Table 1.

[b] Confidence intervals were adjusted for clustering at the surgeon level. The P values shown indicate whether the difference between the overlapping and nonoverlapping groups is significantly different from zero.

[c] High risk refers to 20 857 patients predicted to be at high risk for in-hospital

mortality or postoperative complications on the basis of the characteristics shown in Table 1 and methods described in the text; low risk refers to patients not at high risk. A test of interactions showed no significant differences in the relationship between overlapping surgery and surgery length (P < .001 for F test) across surgery types. A test of interactions showed that surgical overlap was significantly associated with increased surgery length between high-risk vs low-risk patients (P = .12 for test of interactions).

Results were robust to a variety of alternative specifications that incorporated alternative outcomes, alternative definitions of overlap, and alternative methods of adjustment for potential confounders.

Prior studies have generally found no association between overlapping surgery and adverse outcomes,[6-15] with 1 exception.[14] However, these studies had several limitations, the most important being that studies were limited to a single center or type of operation, with some exceptions.[11,12] Because mortality and postoperative complications are fairly rare, such studies may not have been large enough to detect statistically significant differences in their rates. Moreover, the findings of these prior studies may also reflect factors distinctive to the studied hospital. In addition, previous studies have typically compared overlapping operations with nonoverlapping operations for groups including many surgeons. The database in this study included all surgical cases at each institution, allowing an analysis directly comparing overlapping and nonoverlapping operations of the same type performed by the same surgeon at the same institution. Further, this study used a stringent definition of overlap (at least 1 hour of overlap or the entirety of the case if surgical length was less than 60 minutes), ensuring a substantial degree of overlap for cases defined as "overlapping." Some other stud-

ies have used less restrictive definitions of overlap[13] (eg, any overlap regardless of duration), which may bias analyses toward finding no relationship between overlapping surgery and patient outcomes. Indeed, a sensitivity analysis in this study found that using a less restrictive definition of overlap resulted in associations between overlap and the outcomes that were smaller in magnitude than associations from the baseline analysis.

This study strengthens the evidence that overlapping surgery is a reasonable practice for many cases. However, prespecified, exploratory subgroup analyses did find a significant association between overlapping surgery and increased complication and mortality risk for high-risk patients, defined as patients in the upper quartile for predicted mortality or complication risk. In addition, post hoc sensitivity analyses found that overlapping surgery was associated with a significantly increased risk of major postoperative complications. These findings are potentially concerning because any risks associated with overlapping surgery may be expected to occur in precisely this set of outcomes and patient populations. However, these subgroup analyses were exploratory, and the estimated increases in risk were generally small. Overall, the study findings suggest that overlapping surgery is likely to be a safe practice for most patients,

but the exploratory analyses do suggest potential areas for concern and further investigation.

In addition, the study found that overlapping surgery was associated with significantly longer surgical times. While some of this association may be attributable to confounding (ie, longer cases may be selected for overlapping scheduling), it may also be inherent to some elements of overlapping scheduling. For example, portions of the operation may be performed by junior team members, and there may be delays associated with waiting for the surgeon to complete the critical portions of other cases. Increases in surgery length have policy implications, since the operating room is one of the most expensive parts of any hospital. For example, anesthesiologists typically bill for their services by time (around $60 per 15 minutes from private insurers),[32] and the cost of an operating room has been estimated to range from $30 to $60 per minute.[33,34]

Limitations

This study had several limitations. First, it focused on a specific set of operations performed on adults in high-volume medical centers; results may not generalize to pediatric patients or other institutional settings. In particular, the analysis excluded combination operations (ie, combined lumbar/thoracic spine surgery), for which overlapping surgery may be associated with higher risk. Second, surgical complications may occur after discharge, and the data sources used for this analysis did not report postdischarge complications or mortality.

Third, there are some concerns that *International Statistical Classification of Diseases and Related Health Problems, Tenth Revision* codes on discharge abstracts are unreliable indicators of postoperative complications.[35] Fourth, as in all observational studies, selection bias may be present in the data. Surgeons may choose to perform overlapping surgery on relatively low-risk patients, which would bias this study's results toward finding no association. Alternatively, overlapping surgery may be disproportionately performed on higher-risk or higher-complexity patients for whom a

delay in receiving surgery is perceived to be riskier than overlapping scheduling. Surgeons may also select longer, more complex cases for overlapping scheduling. However, sensitivity analyses found few differences in observable characteristics between patients who did and did not have overlapping scheduling, although this does not exclude the possibility of differences in unobservable characteristics (eg, unobserved differences in surgical complexity).

Fifth, the data sources used for this analysis did not specify which personnel had performed the procedures, so the analysis could not adjust for the level of experience (eg, senior vs junior resident) of the surgeon present while the attending surgeon was in another case. Thus, the degree to which any risks from overlapping surgery result from the participation of other team members, and the extent to which surgeons may mitigate these risks by assigning more senior team members to overlapping cases, could not be ascertained. Sixth, the data did not include information on whether operations were concurrent (had overlap in the critical portions of the case)—a situation in which overlapping surgery may be particularly risky. Seventh, not all postoperative complications that may result from overlapping surgery (eg, paralysis or chronic pain in spinal procedures or intraoperative hemorrhage in CABG surgery) could be analyzed because of insufficient detail in the data available for analysis and the inability to identify whether certain conditions like chronic pain were present before surgery.

Conclusions

Among adults undergoing common operations, overlapping surgery was not significantly associated with differences in in-hospital mortality or postoperative complication rates but was significantly associated with increased surgery length. Further research is needed to understand the association of overlapping surgery with these outcomes among specific patient subgroups.

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─── Editor's Note ───

Overlapping Surgery and Perioperative Outcomes

Edward H. Livingston, MD

By the time surgeons complete residency or fellowship training, they must be able to independently perform surgery. This can only occur if surgeons have graded responsibility, meaning that surgical residents must be able to do various parts of an operation on their own until they have mastered the skills necessary to function completely independently. One way this is done is by allowing overlapping surgery—operations in which someone other than the attending surgeon performs part of the operation. In this issue of *JAMA*, Sun and colleagues report outcomes for overlapping surgery to show that this mechanism, which is essential for training surgical residents, is generally safe.[1] Mortality and complications were approximately the same for operations that had substantial overlap (more than 1 hour of the procedure from the time of incision) as compared with no overlap. However, there was a signal that outcomes (mortality and complications) might be worse for high-risk patients, a scenario that makes intuitive sense.

This work appealed to me because it answered an important, unresolved question: Is surgery safe as practiced in academic environments that balance the needs of safe patient care with those required to train the next generation of surgeons? The answer appears to be yes.

This study does not address risks associated with concurrent surgery in which the attending surgeon is not present during a part of the operation considered critical.[2] Major complications attributable to concurrent surgery have been highlighted by the news media,[3] yet whether this practice is safe or acceptable remains unresolved and is not addressed in the current study. How that should be addressed was outlined in *JAMA* previously[2,3] and requires a precise definition of the critical part of the operation that requires the presence of the attending surgeon. That definition should be determined by an independent body of clinicians familiar with the operating room environment and monitoring to ensure that the attending surgeon is in the operating room during that time.[3]

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