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Safety of Overlapping Inpatient Orthopaedic Surgery

A Multicenter Study

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Background: Although overlapping surgery is used to maximize efficiency, more empirical data are needed to guide patient safety. We conducted a retrospective cohort study to evaluate the safety of overlapping inpatient orthopaedic surgery, as judged by the occurrence of perioperative complications.

Methods: All inpatient orthopaedic surgical procedures performed at 5 academic institutions from January 1, 2015, to December 31, 2015, were included. Overlapping surgery was defined as 2 skin incisions open simultaneously for 1 surgeon. In comparing patients who underwent overlapping surgery with those who underwent non-overlapping surgery, the primary outcome was the occurrence of a perioperative complication within 30 days of the surgical procedure, and secondary outcomes included all-cause 30-day readmission, length of stay, and mortality. To determine if there was an association between overlapping surgery and a perioperative complication, we tested for non-inferiority of overlapping surgery, assuming a null hypothesis of an increased risk of 50%. We used an inverse probability of treatment weighted regression model adjusted for institution, procedure type, demographic characteristics (age, sex, race, comorbidities), admission type, admission severity of illness, and clustering by surgeon.

Results: Among 14,135 cases, the frequency of overlapping surgery was 40%. The frequencies of perioperative complications were 1% in the overlapping surgery group and 2% in the non-overlapping surgery group. The overlapping surgery group was non-inferior to the non-overlapping surgery group (odds ratio [OR], 0.61 [90% confidence interval (CI), 0.45 to 0.83]; $p < 0.001$), with reduced odds of perioperative complications (OR, 0.61 [95% CI, 0.43 to 0.88]; $p = 0.009$). For secondary outcomes, there was a significantly lower chance of all-cause 30-day readmission in the overlapping surgery group (OR, 0.67 [95% CI, 0.52 to 0.87]; $p = 0.003$) and shorter length of stay (e^{β}, 0.94 [95% CI, 0.89 to 0.99]; $p = 0.012$). There was no difference in mortality.

Conclusions: Our results suggest that overlapping inpatient orthopaedic surgery does not introduce additional perioperative risk for the complications that we evaluated. The suitability of this practice should be determined by individual surgeons on a case-by-case basis with appropriate informed consent.

Level of Evidence: Therapeutic Level III. See Instructions for Authors for a complete description of levels of evidence.

Overlapping surgery refers to "operations performed by the same primary surgeon such that the start of one surgery overlaps with the end of another."[1] This longstanding practice has been used by surgeons and hospitals to maximize operating room efficiency, with the additional benefit of allowing graduated responsibility to surgical trainees. This practice has been criticized, citing concerns with regard to patient safety, informed consent, and strain to the doctor-patient

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relationship. Advocates for overlapping surgery cite its increased efficiency, its ability to increase availability of specialist surgeons, and an anecdotal belief in safety. Critics of overlapping surgery point to a lack of empirical evidence demonstrating safety and the threat that this practice creates to public trust in hospitals and surgeons[2] as well as concerns from bioethical, professionalism, and legal perspectives[3].

Since investigative journalists at *The Boston Globe* brought the practice of overlapping surgery to public attention in 2015[4], single-center studies have evaluated the safety of overlap in ambulatory orthopaedic surgery[5], inpatient surgery for hip fracture and arthritis[6], and inpatient neurosurgery[7-9]. With the exception of Ravi et al.[6], each of these studies demonstrated that overlapping surgery was not associated with a significant difference in perioperative outcomes. All studies included methodological limitations in risk stratification, generalizability, and statistical power. Using both administrative data and clinical registries to address these shortcomings, Hyder et al. examined all inpatient operations over 3 years at the Mayo Clinic[10]. They concluded that overlapping surgery was safe at their center, but acknowledged limitations in generalizability of their findings. In their population-based, matched-cohort study with a small frequency of overlapping surgery (2.5% of hip fracture operations and 3% of total hip arthroplasties) and without adjustment for comorbidities, Ravi et al. demonstrated an increased risk of complications in the overlapping surgery group.

Given the need for additional empirical data to guide stakeholders and policymakers seeking to protect patient safety, we conducted a cohort study to evaluate the safety of overlapping surgery, as judged by the occurrence of perioperative complications. Data were combined from 5 academic institutions to meet sample size needs, to provide rigorous risk adjustment, and to improve generalizability. We hypothesized that overlapping surgery would be non-inferior to non-overlapping surgery with respect to perioperative complications.

Materials and Methods

Following approval from each institution's review board, we created a retrospective cohort of all inpatient operations performed by orthopaedic surgery faculty members at 5 U.S. academic medical centers from January 1, 2015, to December 31, 2015. We selected this time period to minimize potential practice changes following *The Boston Globe* publication that could adversely bias study data. At each institution, data were gathered from the Vizient Clinical Data Base/Resource Manager (CDM/RM) and operating room databases. Vizient CDM/RM includes case-specific information including age, race, ethnicity, payer, primary and additional procedure codes (including a Clinical Classification Software [CCS] category for the primary procedure)[11], diagnosis codes, admission status, and surgeon. Case-specific risk stratification parameters (admission severity of illness, admission relative expected mortality, diagnosis-related-group-specific expected mortality, and expected length of stay [the first calculated by 3M and latter 3 calculated by Vizient]) were also captured. The diagnosis codes for each case were examined to tabulate an Elixhauser comorbidity index for each patient[12]. Procedure codes and the corresponding CCS category were grouped into 6 clinically relevant subcategories (total joint arthroplasty, spine surgery, fracture treatment, other procedures of bone or joint, soft-tissue procedures, and other) by 2 orthopaedic surgeons. Surgery start (incision) and end (skin closure) times were extracted for each case from each medical center's operating room database. Overlapping surgery was defined as skin incisions open for 2 cases simultaneously with the same attending surgeon. The occurrence and duration of overlapping surgery were tabulated on the basis of surgeon identifier (Fig. 1). The exact events occurring during overlap periods (such as surgical approach, preparation for implants, implantation, or skin closure) were not available with these data, making it impossible to reliably discern whether critical portions of the operations were occurring at the same time. We were also unable to determine how cases were selected by surgeons or hospitals for overlapping scheduling. Additionally, the data set did not provide reliable information across institutions about the level of training of the first assistant in each surgical procedure. The data-sharing agreement among the institutions did not allow us to publicly share the number of cases or the case types or mix performed at each institution.

Primary and secondary clinical outcomes data were extracted from Vizient CDM/RM. Our primary outcome was the occurrence of a perioperative complication, defined as either an Agency for Healthcare Research and Quality Patient Safety

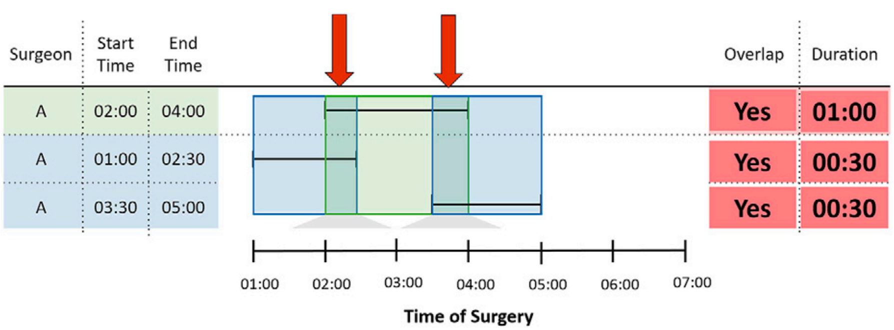

Fig. 1
Identification of overlapping surgeries (skin incision open for 2 cases simultaneously with the same attending surgeon) using skin incision, skin closure, and surgeon identifier information.

Indicator (PSI)[13] or a Centers for Medicare & Medicaid Services Hospital Acquired Condition (HAC)[14], both publicly reported measures for quality of care, within 30 days of the surgical procedure. Our secondary outcomes were all-cause 30-day same-hospital readmission, inpatient mortality, and length of stay. Data-sharing agreements prohibit identification of individual institutions in the presentation of our analysis.

Statistical Methods

Descriptive statistics were used to characterize demographic and clinical characteristics. Categorical variables were summarized by counts and percentages, and continuous variables were summarized by the mean and standard deviation or the median and interquartile range. We evaluated our primary research question of whether overlapping surgery was non-inferior to non-overlapping surgery in terms of perioperative complications using a non-inferiority test in a propensity score-adjusted weighted outcome model, as detailed below. We also compared our perioperative complications among cases that were non-overlapping, overlapping for ≤30 minutes, and overlapping for >30 minutes using a chi-square test.

Power Calculation

For our primary outcome of 30-day complication rate, we defined our non-inferiority margin as 1.5 times the non-overlapping surgery group rate, and we based our a priori sample size calculation on an overall complication rate of 1.6% from the examination of preliminary data from 1 institution. Expecting an overlapping surgery rate of about 50%, under the null hypothesis, our complication rates were ≥1.92% in the overlapping surgery group and 1.28% in the non-overlapping surgery group. On the basis of these rates, we projected 90% power at a significance level of $p < 0.05$ to detect non-inferiority with 5,284 patients per group or 10,568 total cases.

The rationale for a non-inferiority test was that we expected complication rates to be similar between the overlapping surgery group and the non-overlapping surgery group. However, we would not want to penalize the overlapping surgery group if it had fewer complications than the non-overlapping surgery group. Thus, a non-inferiority test enabled us to test whether the overlapping surgery group was not substantially worse than the non-overlapping surgery group in terms of complication rates. We did not perform power calculations for secondary outcomes of length of stay, mortality, and 30-day readmissions.

Modeling Approach

We used an inverse probability of treatment weighting approach rather than conventional multivariable logistic regression because we expected too few complication events to support a logistic regression model that adjusted for all covariates (using the 10 events per predictor rule of thumb)[15]. Our propensity model used multivariable logistic regression predicting overlapping or non-overlapping status from all potential variables related to overlapping or non-overlapping status that were available. These included institution, procedure type, patient demographic characteristics (age, sex, race, comorbidities), admission type, and admission severity of illness. Propensity score distributions were plotted to show the overlap between patients who underwent overlapping surgery and those who underwent non-overlapping surgery. Propensity scores were used to calculate the average treatment effect in treated weights for each subject i, using $W_i = Z_i + e_i \times (1 - Z_i)/(1 - e_i)$, where $Z_i = 1$ indicates overlapping surgery (and $Z_i = 0$, non-overlapping) and e_i indicates the propensity weight[16]. The balance in covariates after adjustment for the average treatment effect in treated weights was checked using standardized differences, calculated using an absolute difference in sample means between subjects in the overlapping and non-overlapping surgery groups divided by their pooled standard deviation[17]. Our primary outcome model predicted perioperative complications from overlapping or non-overlapping surgery status using generalized estimating equation (GEE) logistic regression with robust standard errors and an exchangeable correlation matrix to adjust for the correlation of outcomes within surgeons (clustering within surgeons). We considered a model that nested procedures within surgeons, but it did not converge. The model was implemented in R using the geeglm() function from the geepack package, with the "weights" option to utilize the average treatment effect in treated weights. We also adjusted for important covariates in our outcome model, including procedure type, admission severity of illness, and institution, as recommended to reduce bias from uncontrolled confounding[18]. We ran this model with and without including interactions between institution and overlapping surgery status and between institution and procedure type to allow for the relationship between these variables and complications to vary by institution. We ran a sensitivity analysis dropping the institution with the fewest non-overlapping surgery cases, in case decisions to perform overlapping surgery differed for this institution. This resulted in 12,577 patients from 4 institutions. We ran a second sensitivity analysis for the most common procedure, total joint arthroplasty. This analysis reduced our sample size by 57% to 6,083 patients. It removed potential confounding due to procedure type at the cost of decreased power and generalizability. We ran a third sensitivity analysis that only included surgeons who performed overlapping surgery. This analysis reduced our sample size to 12,889 patients. It minimized potential confounding due to surgeon workflow preferences or practices. We ran a fourth sensitivity analysis that excluded patients with propensity scores of <0.2 and >0.8 from the GEE model. This analysis reduced our sample size to 10,676 patients. It minimized potential confounding due to surgeon workflow preferences or practices.

Secondary outcomes (all-cause 30-day same-hospital readmission, inpatient mortality, and length of stay) were similarly analyzed in outcome models with the average treatment effect in treated weights and adjusting for clustering by surgeon, but we used conventional 2-sided statistical tests to assess significance rather than non-inferiority tests. Our rationale was that these were secondary outcomes, and

TABLE I Descriptive Summary by Overlapping Surgery Status

Variable	Overlapping Surgery Group (N = 5,696)	Non-Overlapping Surgery Group (N = 8,439)	P Value	Test
Age *(yr)*				
Mean and standard deviation	59.4 ± 15.5	56.4 ± 18.5	<0.001	T test
Median (interquartile range)	62 (52, 70)	60 (46, 69)		
Female sex	2,842 (50%)	4,037 (48%)	0.016	Chi-square
Race			<0.001	Chi-square
White	4,588 (81%)	6,651 (79%)		
Asian	70 (1%)	219 (3%)		
Black	791 (14%)	876 (10%)		
Declined	19 (0%)	14 (0%)		
Other	194 (3%)	532 (6%)		
Unavailable	24 (0%)	81 (1%)		
Unknown	10 (0%)	66 (1%)		
Payer			<0.001	Chi-square
Private	2,516 (44%)	3,306 (39%)		
Medicare	2,453 (43%)	3,514 (42%)		
Medicaid	338 (6%)	920 (11%)		
Government: other	15 (0%)	24 (0%)		
Veterans Affairs or TRICARE	94 (2%)	123 (1%)		
Workers' Compensation	82 (1%)	245 (3%)		
Other, self-pay, or unknown	198 (3%)	307 (4%)		
Admission status			<0.001	Chi-square
Elective	4,048 (71%)	4,511 (53%)		
Emergency	364 (6%)	1,934 (23%)		
Trauma center	439 (8%)	556 (7%)		
Urgent	845 (15%)	1,438 (17%)		
Elixhauser comorbidities				
Mean and standard deviation	1.9 ± 1.9	2 ± 2.1		
Median (interquartile range)	1 (1, 3)	1 (0, 3)	0.18	Wilcoxon
Range	0 to 17	0 to 17		
Severity of illness at admission			<0.001	Chi-square
Extreme	118 (2%)	282 (3%)		
Major	560 (10%)	1,211 (14%)		
Moderate	2,789 (49%)	3,920 (46%)		
Minor	2,229 (39%)	3,026 (36%)		
Relative expected mortality at admission			<0.001	Chi-square
Extreme	75 (1%)	139 (2%)		
Major	145 (3%)	492 (6%)		
Moderate	909 (16%)	1,529 (18%)		
Minor	4,567 (80%)	6,279 (74%)		
Surgical procedure type			<0.001	Chi-square
Total joint replacement	3,483 (61%)	2,600 (31%)		
Spine	869 (15%)	2,025 (24%)		
Fracture treatment	700 (12%)	1,928 (23%)		
Other procedures of bone or joint	378 (7%)	1,005 (12%)		
Soft-tissue procedures	212 (4%)	668 (8%)		
Other	54 (1%)	213 (3%)		

continued

TABLE I (*continued*)

Variable	Overlapping Surgery Group (N = 5,696)	Non-Overlapping Surgery Group (N = 8,439)	P Value	Test
Expected length of stay* *(d)*	3 (2.5, 4)	3.7 (2.7, 5.8)	<0.001	Wilcoxon
Diagnosis-related-group-specific expected mortality *(%)*				
Mean and standard deviation	0.3 ± 2.1	0.6 ± 3.1		
Median (interquartile range)	0.1 (0, 0.2)	0.1 (0, 0.3)	<0.001	Wilcoxon
Range	0 to 98.2	0 to 82.4		
Primary outcome				
Patient Safety Indicator or Hospital Acquired Condition	57 (1%)	156 (2%)	<0.001	Chi-square
Secondary outcomes				
Readmission within 30 days for any reason	84 (1%)	358 (4%)	<0.001	Chi-square
Inpatient mortality	9 (0%)	34 (0%)	0.01	Chi-square
Length of stay*	2 (1, 3)	3 (2, 5)	<0.001	Wilcoxon

*The values are given as the median and the interquartile range.

developing non-inferiority tests would require non-inferiority margins to be determined for each outcome, based on evidence provided in the literature. We also provide a conventional 2-sided statistical test result for our primary outcome (complications) to allow for comparability with our secondary outcomes. The inpatient mortality outcome model only included admission severity of illness as a covariate because there were too few events to additionally support institution and procedure type. Because of skewing of the distribution, we used gamma regression for the evaluation of length of stay, and the coefficients and 95% confidence intervals (CIs) were exponentiated (e^{β}) for interpretation as ratios. Significance was assessed at $p < 0.05$ and, aside from our 1-sided non-inferiority test for perioperative complications, all tests were 2-sided. Statistical analysis was performed in R version 3.4 (R Foundation for Statistical Computing). Additional information with regard to implementation of the non-inferiority analysis is included in the Appendix.

Results

There were 14,135 operations performed by 215 surgeons (range, 15 to 76 surgeons among the 5 institutions). Overlapping surgery (skin incisions open in 2 separate rooms) of any duration occurred in 40% of surgical procedures. Among those cases with overlapping surgery, the mean duration of overlapping surgery was 53 minutes and the median duration of overlapping surgery was 37 minutes (interquartile range, 17 to 71 minutes). Differences in age, sex, race, and payer between groups are demonstrated in Table I. There were significantly more elective cases ($p < 0.001$) in the overlapping surgery group (71%) compared with the non-overlapping surgery group (53%). There was a significantly higher proportion of total joint replacement cases ($p < 0.001$) in the overlapping surgery group (61%) compared with the non-overlapping surgery group (31%). The combined percentage of patients with extreme or major admission severity of illness was 12% in the overlapping surgery group and 17% in the non-overlapping surgery group ($p < 0.001$) (Table I). Relative expected mortality at admission and diagnosis-related-group-specific expected mortality were lower in the overlapping surgery group (Table I).

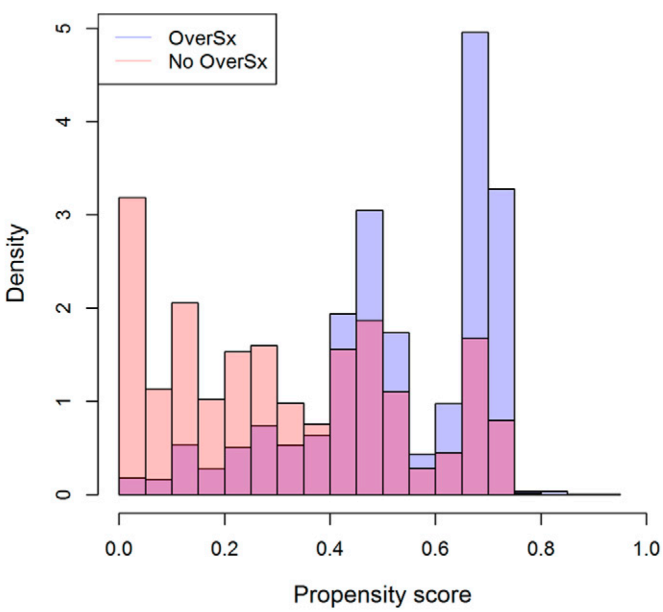

Fig. 2

Propensity score distributions between the overlapping surgery (OverSx: lavender) group and the non-overlapping surgery (No OverSx: peach) group show notable overlap (overlap indicated in purple). There were 5 subjects with scores outside the overlapping region who were dropped from our analysis. The area of the distributions was scaled to be equal between the groups to improve visualization.

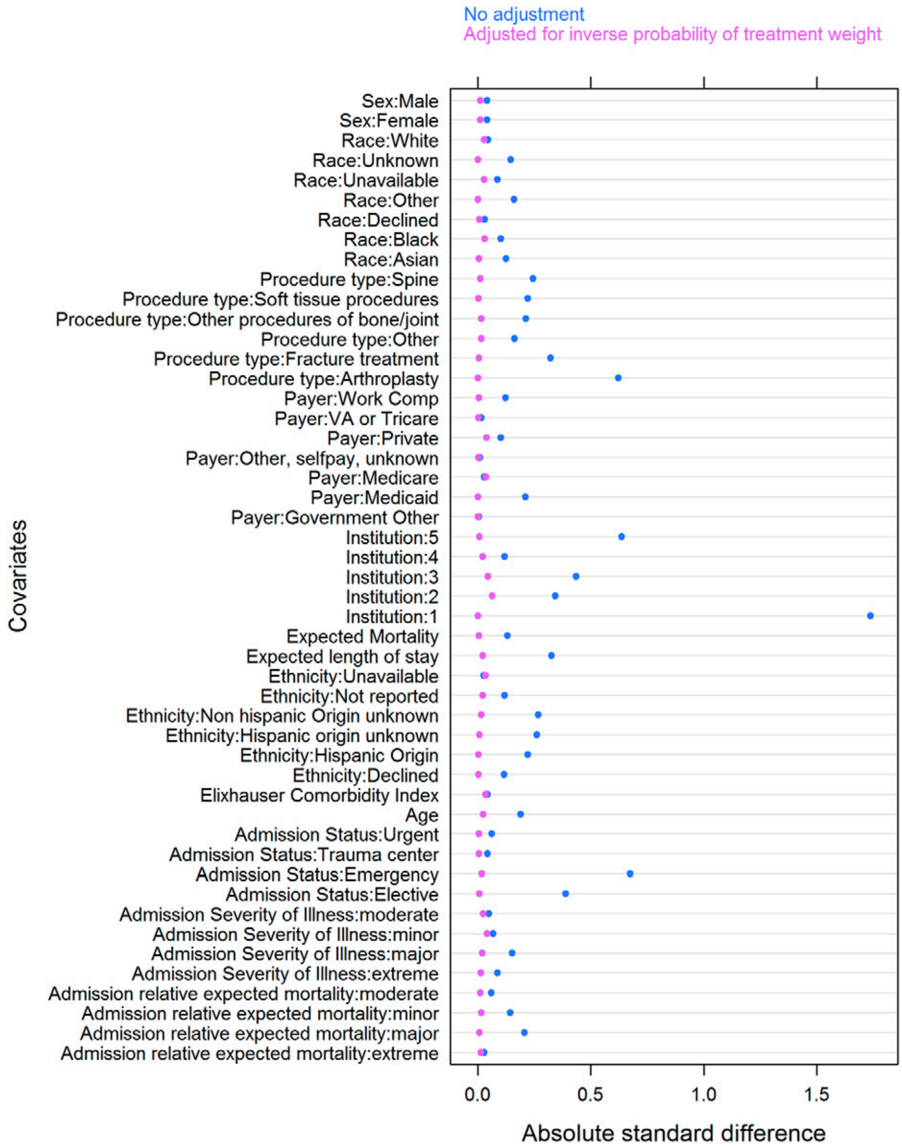

Fig. 3

Standardized differences between overlapping and non-overlapping surgery groups for all covariates included in the regression model. Standardized differences were calculated as the absolute difference in the sample means between the overlapping and non-overlapping surgery groups divided by their pooled standard deviation. Light purple indicates standardized differences with adjustment using inverse probability of treatment weighting, and blue indicates standardized differences without adjustment. All standardized differences with adjustment (light purple) are <0.2, indicating balance among the covariates between the 2 groups. Work Comp = Workers' Compensation and VA = Veterans Affairs.

Univariate analysis demonstrated a significantly lower frequency of perioperative complications in the overlapping surgery group (1% [57 events among 5,696 cases]) than in the non-overlapping surgery group (2% [156 events among 8,439 cases]). Similarly, there was a significant difference ($p < 0.001$) in perioperative complications among non-overlapping surgery cases (1.8%), cases overlapping for ≤30 minutes (0.9%), and cases overlapping for >30 minutes (1.1%). Inpatient mortality was uncommon in both groups (43 events total: 9 in the overlapping surgery group and 34 in the non-overlapping surgery group; $p = 0.01$). Thirty-day all-cause hospital readmission was lower ($p < 0.001$) in the overlapping surgery group (1%) than in the non-overlapping surgery group (4%). The observed length of stay was also lower in the overlapping surgery group (median, 2 days [interquartile range, 1 to 3 days]) than in the non-overlapping surgery group (median, 3 days [interquartile range, 2 to 5 days]).

Overlap was high between propensity score distributions of those with and without overlapping surgery (Fig. 2), except for 5 subjects who had scores outside of the overlap region and were dropped from our analysis. Inverse probability of treatment weighting[19] achieved balance (standardized difference

TABLE II GEE Model for the Primary Outcome, Weighted by Propensity Scores and Adjusting for Clustering within Surgeons*

Variable	OR*	P Value
Overlapping surgery†	0.61 (0.43 to 0.88)	0.009
Institution		
Institution 1	1.27 (0.54 to 2.96)	0.58
Institution 2	2.77 (1.62 to 4.73)	<0.001
Institution 3	Reference	
Institution 4	0.51 (0.26 to 1.01)	0.054
Institution 5	0.52 (0.31 to 0.86)	0.012
Surgical procedure type		
Total joint replacement	Reference	
Spine	2.89 (1.69 to 4.94)	<0.001
Fracture treatment	1.58 (0.81 to 3.05)	0.18
Other procedures of bone or joint	2.68 (1.34 to 5.35)	0.005
Soft-tissue procedures	3.86 (1.97 to 7.57)	<0.001
Other	4.62 (1.65 to 12.87)	0.003
Admission severity of illness		
Minor	Reference	
Moderate	2.30 (1.31 to 4.06)	0.004
Major	5.20 (2.52 to 10.73)	<0.001
Extreme	25.41 (12.09 to 53.40)	<0.001

*The values are given as the OR, with the 95% CI in parentheses, for conventional hypothesis testing. †For our non-inferiority testing of overlapping surgery, the OR (and 90% CI) was 0.61 (0.45 to 0.83), and the 1-sided p value was p < 0.001.

<0.2) in all measured covariates, indicating that the overlapping surgery group and the non-overlapping surgery group were similar with regard to covariates after weighting was applied (Fig. 3). Our outcome regression model, adjusting for the average treatment effect in treated weights and potential confounders, demonstrated that the overlapping surgery group was non-inferior with regard to perioperative complications (odds ratio [OR], 0.61 [90% CI, 0.45 to 0.83]; p < 0.001 compared with an OR of 1.51 in a non-inferiority test). Furthermore, conventional hypothesis testing showed a significantly reduced odds of perioperative complications in the overlapping surgery group (OR, 0.61 [95% CI, 0.43 to 0.88]; p = 0.009). The risk of perioperative complications was associated with institution, procedure type (with all other procedure types associated with greater risk than total joint arthroplasty), and admission severity of illness (with a direct association of greater severity of illness with perioperative complications) (Table II). The relationship between overlapping surgery and complications was similar in magnitude and significance in the models with and without interactions between institution and overlapping surgery status and between institution and procedure type (data not shown). The results for the secondary outcomes of 30-day all-cause readmission demonstrated significantly lower odds of readmission in the overlapping surgery group (OR, 0.67 [95% CI, 0.52 to 0.87]; p = 0.003) and a shorter length of stay (e^{β}, 0.94 [95% CI, 0.89 to 0.99]; p = 0.012) after adjusting for institution, procedure type, and admission severity of illness (Table III). After adjusting for admission severity of illness, there was no difference in the odds of inpatient mortality (OR, 1.05 [95% CI, 0.54 to 2.47]; p = 0.71).

Sensitivity Analyses

We performed a sensitivity analysis in which 1 institution with a lower percentage of overlapping cases was excluded. The results (reported in the Appendix) were similar to the full model with regard to coefficient direction and significance. We performed an additional sensitivity analysis including only patients who underwent total hip or knee arthroplasty. For this analysis, we again found the overlapping surgery group to be non-inferior to the non-overlapping surgery group, with a less pronounced effect (8% lower odds of complications [OR, 0.92 (90% CI, 0.6 to 1.43); p = 0.032]). With conventional hypothesis testing, the complication rate was not significantly different between the overlapping surgery group and the non-overlapping surgery group (OR, 0.92 [95% CI, 0.55 to 1.55]; p = 0.76). We performed a third sensitivity analysis including only surgeons who performed overlapping surgery. For this analysis, we again found the overlapping surgery group to be non-inferior to the non-overlapping surgery group, with a slightly less pronounced effect (OR, 0.61 [90% CI, 0.45 to 0.83]; p = 0.008). With conventional hypothesis testing, the complication rate was significantly lower in the overlapping surgery group compared with the non-overlapping surgery group (OR, 0.61 [95% CI, 0.42 to 0.88]; p < 0.001). In our fourth sensitivity analysis, removing patients with a propensity score of <0.2 or >0.8 from the model, we again found the

TABLE III GEE Model for the Secondary Outcomes of All-Cause 30-Day Hospital Admission, Length of Stay, and Inpatient Mortality

Outcome	Estimate Associated with Overlapping Surgery	P Value
Length of stay*	0.94 (0.89 to 0.99)†	0.012
All-cause 30-day hospital readmission*	0.67 (0.52 to 0.87)‡	0.003
Inpatient mortality§	1.05 (0.54 to 2.47)‡	0.71

*The models for all-cause 30-day hospital admission and length of stay are adjusted for institution, procedure type, and admission severity of illness. †The value is given as the ratio in outcomes (with the 95% CI in parentheses) between the overlapping surgery group and the non-overlapping surgery group. ‡The values are given as the odds ratio, with the 95% CI in parentheses. §Because of the low number of inpatient deaths (43 cases total), the model for inpatient mortality adjusts only for the admission severity of illness.

overlapping surgery group to be non-inferior to the non-overlapping surgery group, with a slightly less pronounced effect (OR, 0.61 [90% CI, 0.42 to 0.90]; p = 0.012). With conventional hypothesis testing, the complication rate was significantly lower in the overlapping surgery group compared with the non-overlapping surgery group (OR, 0.61 [90% CI, 0.44 to 0.84]; p < 0.001).

Discussion

Perioperative risk is multifactorial, with numerous patient, procedure, surgeon, and hospital-specific factors contributing to the overall safety of an individual operation[20]. As demonstrated in our multivariable analysis of inpatient orthopaedic operations, patient comorbidities, procedure type, and institution were all significantly associated with the likelihood of a postoperative patient safety event. After adjusting for these factors, we demonstrated that having overlapping surgery was not an independent risk factor for perioperative patient safety events. We found that patients who had overlapping surgery were at significantly lower risk of patient safety events and 30-day all-cause readmission; these findings likely reflect characteristics influencing surgical outcomes that we cannot reliably measure with these data, such as individual procedure complexity and surgeon experience. Using administrative data, we cannot reliably determine the complexity of cases and therefore cannot examine the relationship between case complexity and overlap. Future investigation into reasons for a lower complication rate among patients having overlapping surgery are warranted, but are beyond the scope of this investigation.

A relatively small portion of the surveyed public is aware of the practice of overlapping surgery[21]. Empirical investigation with regard to the safety of overlapping surgery is needed to justify the perceived risks associated with it. Prior single-center studies have demonstrated the relative safety of overlapping surgery[5,7-10], and our study was designed to address methodological limitations of prior studies (including risk stratification, statistical power, and approach to hypothesis testing). Our results corroborate those of most prior studies, lending further credence to the belief that overlapping surgery itself is not an independent risk factor for an adverse outcome. Our findings are in contrast to those of Ravi et al., who demonstrated an increased risk of complications in patients undergoing hip fracture surgery or total hip arthroplasty in Ontario, Canada[6]. The populations assessed in our study and the study by Ravi et al. may be inherently different because of contrasts in health-care systems (most strikingly, the overlapping surgery rate was 40% in the former and 2.5% to 3% in the latter) and the breadth of procedures studied (all inpatient orthopaedic surgery in our study; only hip fracture surgery and total hip arthroplasty in the study by Ravi et al.). However, the subgroup analysis that we conducted, which only included patients who underwent total hip or knee arthroplasty, demonstrated a similar lack of increased risk in the overlapping surgery group. We have also included adjustment for perioperative medical risk in our regression models.

As surgeons and hospitals determine the role and appropriateness of overlapping surgery at their institutions, it should be noted that the public desires greater transparency about the rationale and processes of overlapping surgery[21,22]. Mello and Livingston provided guidance for communicating with patients, suggesting that a discussion be conducted in advance of surgery about the surgeon's exact involvement in the surgery, the potential delegation of some surgical responsibility to trainees or assistants, and the possibility of overlapping surgery[2]. Furthermore, a recent update to the American College of Surgeons Statement on Principles makes clear the expectations for surgeons with regard to the conduct of overlapping surgery and securing informed consent[23].

The current investigation had limitations inherent to its study design. We used an administrative data source to obtain the sample size needed to examine non-inferiority of overlapping surgery. The use of Vizient data for clinical outcomes provided uniformity of reporting across institutions, but it relies on accuracy of coding and validity of outcomes measures. Prior validation of a Vizient clinical database with institutional data has demonstrated reliability in reporting demographic characteristics and postoperative complications[24]. Additionally, we used risk adjustment parameters (such as admission severity of illness and expected mortality) that were created by third parties (3M and Vizient). We did not independently validate these risk adjustment parameters, but they are used at academic institutions for peer benchmarking and have been utilized in other empirical studies of inpatient and perioperative outcomes[25,26]. Although our study evaluated the effect of overlapping surgery on measures of postoperative patient safety, we acknowledge that the effect of overlapping surgery on patient satisfaction and longer-term (>30-day) patient outcomes (including revision surgery rates and radiographic assessments such as implant alignment) remains unclear. Although we performed an analysis based on the amount of overlap, we did not have any information with regard to which steps were occurring during overlapping times (because it is not the current practice at our institutions to record when the critical portions of surgical procedures are occurring). As institutions move toward more granular record-keeping of events during surgical procedures and form policies with regard to the critical portions of the surgical procedure, the duration and type of overlap deserve future investigation[1]. Additionally, our analysis indicates that there are many other factors that contribute to perioperative complications. Procedure type may play an important role in determining the appropriateness of overlapping surgery. In our second sensitivity analysis, we performed an analysis of total hip or knee arthroplasty that resulted in similar findings (but to a lesser extent). Prior literature has demonstrated the importance of surgeon volume as it relates to complications and outcomes[27,28]. Privacy considerations in our data-sharing agreements prohibit stratification of outcomes by individual surgeons, but we adjusted for the correlation of outcomes within surgeons. Furthermore, the implications of overlapping surgery likely extend beyond the short-term perioperative complications that we analyzed; future investigation must include long-term patient-reported outcomes. Lastly, our findings are based on an analysis of data for inpatient orthopaedic surgery cases in the United States. The varying risk profiles of other types of surgery (outpatient or ambulatory surgery, different surgical disciplines) should be considered before our findings are generalized or applied broadly.

Although perioperative risk depends on numerous other factors, our results provide empirical data indicating that overlapping inpatient orthopaedic surgery is non-inferior with regard to the occurrence of postoperative patient safety events. It is acknowledged that overlapping surgery is a high-stakes form of multitasking for both surgeon and staff[2]. Individual surgeons must make a determination whether they can adequately supervise operations that overlap in 2 separate rooms. In addition to the category of procedure, the complexity of individual procedures (such as primary total joint arthroplasty compared with tumor reconstruction arthroplasty) likely has a large influence on the selection of cases for overlapping surgery. When performed at its optimal capacity, overlapping surgery can be beneficial to all parties involved, provided that appropriate measures are taken to prioritize patient safety, to ensure informed consent, and to eliminate the chance of concurrent surgery (in which critical portions of the cases occur simultaneously[23]). Although the practice of scheduling overlapping cases may have the appearance of only serving the surgeon and/or hospital, this increase in surgical capacity can also be seen as improving access to care for patients desiring a surgical procedure sooner. Our model indicates that other factors (patient, procedure, and institution-specific) are associated with postoperative complications, suggesting that the appropriateness of overlapping surgery is potentially case-specific. Because patient awareness of the rationale and logistics of this practice is lacking, additional studies are needed to evaluate both patient understanding and acceptance of overlapping surgery. It is incumbent on surgeons who perform overlapping surgery to disclose this practice to their patients and to collect patient-reported outcomes to ensure continuing patient satisfaction and to demonstrate benefit to society.

Appendix

eA Text describing the non-inferiority analysis implementation and the 4 sensitivity analyses along with tables showing the GEE models for these outcomes are available with the online version of this article as a data supplement at jbjs.org (http://links.lww.com/JBJS/E959). ■

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