JNS

CLINICAL ARTICLE

Complication rate of overlapping versus nonoverlapping functional and stereotactic surgery: a retrospective cohort study

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OBJECTIVE Overlapping surgery, in which one attending surgeon manages two overlapping operating rooms (ORs) and is present for all the critical portions of each procedure, is an important policy that improves healthcare access for patients and case volumes for surgeons and surgical trainees. Despite several studies demonstrating the safety and efficacy of overlapping neurosurgical operations, the practice of overlapping surgery remains controversial. To date, there are no studies that have investigated long-term complication rates of overlapping functional and stereotactic neurosurgical procedures. The primary objective of this study was to investigate the 1-year complication rates and OR times for nonoverlapping versus overlapping functional procedures. The secondary objective was to gain insight into what types of complications are the most prevalent and test for differences between groups.

METHODS Seven hundred eighty-three functional neurosurgical cases were divided into two cohorts, nonoverlapping (n = 342) and overlapping (n = 441). The American Society of Anesthesiologists (ASA) scale score was used to compare the preoperative risk for both cohorts. A complication was defined as any surgically related reason that required readmission, reoperation, or an unplanned emergency department or clinic visit that required intervention. Complications were subdivided into infectious and noninfectious. Chi-square tests, independent-samples t-tests, and uni- and multivariable logistic regressions were used to determine significance.

RESULTS There were no significant differences in mean ASA scale score (2.7 ± 0.6 for both groups, p = 0.997) or overall complication rates (8.8% nonoverlapping vs 9.8% overlapping, p = 0.641) between the two cohorts. Infections accounted for the highest percentage of complications in both cohorts (46.6% vs 41.8%, p = 0.686). There were no statistically significant differences between mean in-room OR time (187.5 ± 141.7 minutes vs 197.1 ± 153.0 minutes, p = 0.373) or mean open-to-close time (112.2 ± 107.9 minutes vs 121.0 ± 123.1 minutes, p = 0.300) between nonoverlapping and overlapping cases.

CONCLUSIONS There was no increased risk of 1-year complications or increased OR time for overlapping functional and stereotactic neurosurgical procedures compared with nonoverlapping procedures.

https://thejns.org/doi/abs/10.3171/2022.8.JNS212363

KEYWORDS overlapping surgery; functional neurosurgery; concurrent; stereotactic; outcomes; complications

Overlapping surgery is defined as one attending surgeon managing two operating rooms (ORs) and being present for the critical portions of each procedure. Neurosurgeons practicing at academic centers commonly use overlapping surgery to increase OR utilization for long procedures (with significant preparation, opening, and closing time), high case volumes, and increased OR turnover time. In 2017, the *Boston Globe* published an article on the practice of overlapping surgery, highlighting a tragic case of a 45-year-old man who

ABBREVIATIONS ASA = American Society of Anesthesiologists; DBS = deep brain stimulation; IPG = internal pulse generator; OR = operating room; PNS = peripheral nerve stimulator; VNS = vagus nerve stimulator.

SUBMITTED October 8, 2021. **ACCEPTED** August 3, 2022.
INCLUDE WHEN CITING Published online September 30, 2022; DOI: 10.3171/2022.8.JNS212363.

became quadriplegic after an 11-hour complex cervical procedure. The subsequent proceedings from litigation of the case revealed that the orthopedic surgeon was running two ORs at the time of the patient's injury. The jury ultimately ruled that the overlapping procedures did not play a role in the patient's quadriplegia.[1] Despite this ruling and several large-volume studies indicating the safety and efficacy of overlapping surgery, the topic remains controversial.

The existing literature suggests there is no difference in 30-day reoperation rates, surgical outcomes, or morbidity and mortality of overlapping surgery compared with nonoverlapping surgery.[2–9] Several studies have suggested that overlapping surgery has significantly longer OR times than nonoverlapping surgery, but this is not consistent throughout the literature.[3] Due to public pressure, some healthcare centers have prohibited overlapping surgery despite clear evidence of its safety.[10] Furthermore, other than one relatively small study investigating deep brain stimulation (DBS) lead placement accuracy in overlapping cases, there have been no studies that have examined overlapping functional and stereotactic surgeries.[11] At a time when the COVID-19 pandemic has demonstrated the importance of healthcare access and generated a backlog of elective and nonurgent cases, the topic of overlapping surgery is now more important than ever. Thus, more evidence is needed to support the continued use of overlapping surgery, particularly in the field of functional and stereotactic neurosurgery.

The purpose of this study was to investigate the safety of overlapping surgery for functional and stereotactic neurosurgical procedures. The primary objective was to compare the rates of complications within 1 year of nonoverlapping surgeries to overlapping surgeries. The secondary objective was to compare the types of complications, specifically infectious and noninfectious, in nonoverlapping surgeries to overlapping surgeries. The tertiary objective was to compare OR time, both in-room and open-to-close time, for nonoverlapping and overlapping surgeries.

Methods

Design

A retrospective review was performed on all elective functional neurosurgical cases performed from January 1, 2014, to January 1, 2016, by three neurosurgeons (authors J.T.W., N.M.B., and R.E.G.) at one academic hospital (Emory University). The types of procedures included were DBS stages 1 (electrode implantation) and 2 (connection to internal pulse generator [IPG]); electrode placement with stereoelectroencephalography, grids, and strips; peripheral nerve stimulator (PNS) trial placement and permanent implantation; vagus nerve stimulator (VNS) placement; intrathecal pump trials and permanent placement, and exchanges; and exchange of IPGs or reservoirs for these devices. Cases were excluded if they were emergent, urgent, or nonfunctional/stereotactic (e.g., trauma, shunting, spine, washouts). The remaining cases were divided into two cohorts: nonoverlapping and overlapping (two patients in separate ORs with an overlapping time interval).

A complication was defined as any intraoperative complication or postoperative surgically related reason that required readmission, reoperation, unplanned emergency department visit, or clinic visit that led to an intervention. Complications were stratified into infectious and noninfectious, and further subdivided into specific type of complication.

To compare the nonoverlapping and overlapping cohorts, data were collected on patient demographics and operative data, including age, sex, presurgical American Society of Anesthesiologists (ASA) scale score, type of procedure performed, and the presence of a co-surgeon, fellow or senior resident (postgraduate year [PGY] 5–8), or junior resident (PGY1–4) for the procedure.

Statistical Analysis

Differences in categorical variables were assessed using the chi-square test. Independent-samples t-tests were used to compare means of parametric continuous data, and the Mann-Whitney U-test was used to compare nonparametric data. Parametric results are reported below due to the central limit theorem, stating that data approach normality given a sufficiently large sample size (i.e., $n > 30$). All tests were two-sided, and p values < 0.05 were considered statistically significant for all comparisons. Odds ratios were calculated to measure associations between risk factors and 1-year complications. Covariate selection was driven by available knowledge and the clinical plausibility of potential confounders, taking into the consideration the hypothesis of interest. The adjusted odds ratio and its 95% confidence interval (CI) were calculated for each risk factor in the presence of others in the final model. All analyses were performed using JMP Pro data analysis software (version 15.1.0, SAS Institute).

Results

A total of 1573 cases for these three surgeons over this period were screened. Of these 1573 cases, 783 met inclusion criteria. Forty-four percent of cases were nonoverlapping (n = 342) and 56% were overlapping (n = 441; Table 1). There were no statistically significant differences in mean age (52.3 ± 18.2 vs 53.7 ± 17.4 years, p = 0.279); sex (56.0% male vs 54.0% male, p = 0.442); preoperative ASA scale score (2.7 ± 0.6 for both groups, p = 0.997); or the presence of a co-surgeon (5.3% vs 5.4%, p = 0.945), fellow or senior resident (27.8% vs 31.3%, p = 0.288), or junior resident (66.9% vs 63.0%, p = 0.256) between the nonoverlapping and overlapping cohorts.

For types of surgery, there were no statistically significant differences between proportion of DBS-related procedures (51.2% vs 56.5%, p = 0.127), PNS procedures (9.8% vs 12.2%, p = 0.295), VNS procedures (11.6% vs 13.3%, p = 0.462), and intrathecal pump procedures (12.5% vs 13.8%, p = 0.585) between the nonoverlapping and overlapping cohorts. There were significantly higher proportions of electrode placement procedures (14.9% vs 4.1%, p < 0.001) in the nonoverlapping cohort compared with the overlapping cohort (Table 1).

There were no significant differences between overall complication rates (8.8% nonoverlapping vs 9.8% overlapping, p = 0.641). Infections were the most common com-

TABLE 1. Patient and surgery characteristics

Variable	Nonoverlapping	In-Room Overlapping	p Value
Patient characteristics			
No.	342	441	
Mean age ± SD, yrs	52.3 ± 18.3	53.7 ± 17.4	0.279
Sex, % male	56.0	54.0	0.442
Mean preop ASA score ± SD	2.7 ± 0.6	2.7 ± 0.6	0.997
Staffing, %			
Presence of a co-surgeon	5.3	5.4	0.945
Presence of a fellow/senior resident	27.8	31.3	0.288
Presence of junior resident	66.9	63.0	0.256
Types of surgery, %			
DBS	51.2	56.5	0.127
PNS	9.8	12.2	0.295
VNS	11.6	13.3	0.462
Intrathecal pump	12.5	13.8	0.548
Electrode placement	14.9	4.1	**<0.001**
Complications, %			
Total complication rate	8.8	9.8	0.641
Infectious complication rate	46.6	41.8	0.686
Mean OR time ± SD, mins			
In-room time	187.5 ± 141.7	197.1 ± 153.0	0.373
Open-to-close time	112.2 ± 107.9	121.0 ± 123.1	0.300

Boldface type indicates statistical significance.

plication in both cohorts (46.6% vs 41.8%, p = 0.686; Table 1). There were no significant differences in the second and third most common complications of hardware malfunction (20.0% vs 18.6%, p = 0.882) and dehiscence/erosion (16.6% vs 11.6%, p = 0.829).

Univariable logistic regression demonstrated that independent of whether the surgery was overlapping or nonoverlapping, there may have been a significantly increased rate of complications when there was a senior resident (OR 3.5, 95% CI 0.81–15.16, p = 0.015) compared with when the case was attending only (reference). DBS-related procedures were associated with a significantly lower rate of complications (OR 0.51, 95% CI 0.31–0.84, p = 0.008). PNS-related procedures were associated with a significantly higher rate of complications (OR 3.09, 95% CI 1.72–5.56, p < 0.001). Intrathecal pumps were associated with a significantly higher rate of complications (OR 2.23, 95% CI 1.24–4.02, p = 0.007; Table 2).

Multivariable logistic regression showed that there was no significant increased risk of complications for overlapping compared with nonoverlapping surgery (OR 1.03, 95% CI 0.62–1.72, p = 0.90). Of the 10 factors included in the regression, only the presence of a senior resident was associated with a statistically significantly higher risk of complications within 1 year (OR 3.13, 95% CI 0.71–13.86, p = 0.02; Table 3).

There were no significant differences for the mean in-room time (187.5 ± 141.7 minutes vs 197.1 ± 153.0 minutes, p = 0.373) or mean open-to-close time (112.2 ± 107.9 minutes vs 121.0 ± 123.1 minutes, p = 0.300) between the nonoverlapping and overlapping cohorts (Table 4).

Discussion

The existing neurosurgical literature suggests that overlapping surgery is a safe practice with no difference in surgical outcome and no increased risk of 30-day reoperation or morbidity and mortality. Despite this research, overlapping surgery remains a contentious topic, with some hospitals prohibiting the practice. Most of the existing research is limited to 30- or 90-day outcomes, and there have been no studies that have examined the long-term outcomes of overlapping surgery in functional and stereotactic neurosurgical cases. Thus, we aimed to elucidate the safety of overlapping surgery in functional procedures by investigating rates of 1-year complications in nonoverlapping and overlapping cases.

Nonoverlapping Versus Overlapping Cases

There were no statistically significant differences in age, sex, or preoperative ASA scale score between the nonoverlapping and overlapping patients. Unlike some previous research that has shown overlapping procedures to be more routine with healthier patients and lower ASA scale scores,[2,7] our demographic data suggest that the patients in each group were similar with regard to preoperative risk. There was no difference in the staffing of the nonoverlapping and overlapping cases, with co-surgeons, fellows/senior residents, and junior residents present for an equal proportion of cases in each cohort. This homogeneity helps to control for the variable of surgeon experience, which could have an impact on the dependent variable of this study (rate of complications).

There was also very little difference in the types of procedures performed in the two cohorts, showing that there was a relatively homogenous representation of cases. There was a larger proportion of electrode placement cases in the nonoverlapping cohort, likely due to logistical issues such as scheduling (e.g., not having two ORs available at the same time) and limited resources such as a finite number of planning stations, robots, and frames.

We found no significant difference in the rate of 1-year complications between the nonoverlapping and overlapping cohorts, which was true for both infectious and noninfectious complications as well as the subgroups of complications, such as hardware malfunction and dehiscence/erosion. This result is consistent with the existing literature that has found no difference in rates of complications or morbidity and mortality between groups,[2–9] but suggests that this lack of difference extends well beyond the 30- and 90-day outcomes that have been previously reported.

The complication rates were relatively high for both cohorts investigated in this study (8.8% nonoverlapping vs 9.8% overlapping). Two factors account for this phenomenon. First, as previously stated in the *Methods*, our

TABLE 2. Univariable logistic regression: risk factors associated with 1-year total complications among 783 functional neurological patients

Risk Factor	Incidence/Total Complications	%	Odds Ratio	95% CI	p Value*
Procedure					
In-room overlapping	43/441	9.8	1.12	0.69–1.83	0.64
Nonoverlapping	30/342	8.8	Ref		
Age per 10-yr increase	—	—	0.92	0.80–1.05	0.20
Sex					
Female	34/351	9.7	1.08	0.67–1.75	0.75
Male	39/432	9.0	Ref		
ASA score					
3–4	50/538	9.3	0.99	0.59–1.66	0.97
1–2	23/245	9.4	Ref		
Staff					
Junior resident	37/507	7.3	1.61	0.38–6.94	0.72
Senior resident	34/233	14.6	3.50	0.81–15.16	**0.015**
Attending only	2/43	4.7	Ref		
DBS					
Yes	28/418	6.7	0.51	0.31–0.84	**0.008**
No	45/365	12.3	Ref		
PNS					
Yes	18/86	20.9	3.09	1.72–5.56	**<0.001**
No	55/697	7.9	Ref		
VNS					
Yes	4/97	4.1	0.39	0.14–1.08	0.07
No	69/686	10.1	Ref		
Intrathecal pump					
Yes	17/102	16.7	2.23	1.24–4.02	**0.007**
No	56/681	8.2	Ref		
Electrode placement					
Yes	5/68	7.4	0.76	0.29–1.94	0.56
No	68/715	9.5	Ref		

Ref = reference.
One-year incidence rate of total complications = 73/783, 9.3% (95% CI 7.5%–11.6%). Boldface type indicates statistical significance.
* p value obtained from a Wald chi-square test that the regression coefficient for the risk factor is not equal to zero.

definition of complication was broad and included any surgically related reason for a previously unplanned emergency department or clinic visit, including increased pain. Second, we included peripheral nerve surgeries, many of which were PNSs, that had a threefold increased risk of developing a complication within 1 year compared with other procedures included in the study. PNS-related complications were typically infection, dehiscence/migration, and hardware malfunction. Complications for PNSs have been cited to be as high as 30%–40% in the neurosurgical literature.[12] Intrathecal pumps also had a significantly higher risk of complications than other procedures, which contributed to the relatively high rate of complications in this study. This finding is consistent with existing literature that suggests that intrathecal pumps can be expected to have rates of complications as high as 37% in some patient populations.[13]

Furthermore, overlapping procedures did not have longer OR times than nonoverlapping cases. This was true for both total in-room time and open-to-close time. As previously noted, there are mixed findings in the current neurosurgical literature regarding OR time for overlapping procedures. Some studies have found that overlapping surgeries have prolonged OR time, while others have found no difference. The variable results from these existing studies are likely due to the types of procedures included and the fluid definition of overlapping in the literature. Overlapping can be defined as in-room overlapping (two patients in separate ORs with an overlapping time interval) or, more specifically, skin-to-skin overlapping (two patients in separate ORs open on the operating table with an overlapping time interval). The cases included in our study encompass both of these definitions (Fig. 1).

TABLE 3. Multivariable logistic regression: risk factors associated with 1-year total complications among 783 functional neurological patients

Risk Factor	Odds Ratio	95% CI*	p Value†
Procedure			
In-room overlapping	1.03	0.62–1.72	0.90
Nonoverlapping	Ref		
Age per 10-yr increase	0.88	0.74–1.06	0.17
Sex			
Female	1.04	0.62–1.73	0.89
Male	Ref		
ASA score			
3–4	1.17	0.66–2.07	0.59
1–2	Ref		
Staff			
Junior resident	1.35	0.30–6.00	0.52
Senior resident	3.13	0.71–13.86	**0.02**
Attending only	Ref		
DBS			
Yes	1.04	0.12–8.71	0.98
No	Ref		
PNS			
Yes	3.36	0.39–28.80	0.27
No	Ref		
VNS			
Yes	0.47	0.05–4.73	0.52
No	Ref		
Intrathecal pump			
Yes	2.51	0.29–21.61	0.40
No	Ref		
Electrode placement			
Yes	0.75	0.08–7.25	0.80
No	Ref		

Boldface type indicates statistical significance.
* 95% Wald CI of an individual odds ratio given the other predictors are in the model. For a given predictor variable with a 95% CI, we can conclude that we are 95% confident that upon repeated studies, 95% of the CIs would include the "true" population odds ratio.
† These are the p values testing the null hypothesis that an individual predictor's regression coefficient is zero, given the other predictor variables are in the model.

TABLE 4. Mean OR time between nonoverlapping and overlapping cases

OR Time	Mean Time ± SD, mins		p Value
	Nonoverlapping	In-Room Overlapping	
In-room time	187.5 ± 141.7	197.1 ± 153.0	0.373
Open-to-close time	112.2 ± 107.9	121.0 ± 123.1	0.300

Overlapping Versus Concurrent Surgery

It is important to note that overlapping surgery is distinct from concurrent surgery. Overlapping surgery refers to the practice of one attending surgeon managing two ORs simultaneously but being present for all the critical portions of both procedures. Concurrent surgery is when one attending is managing two ORs simultaneously and may miss some of the critical portions of one or both procedures. Concurrent surgery has been condemned by the American Association of Neurological Surgeons, the American Board of Neurological Surgery, the Society of Neurological Surgeons, and the Congress of Neurological Surgeons in a position statement on the intraoperative responsibility of the primary neurosurgeon.[14] These same societies have published a detailed description of guidelines and restrictions when performing overlapping surgery, including informed consent of the patient, the need for a qualified backup neurosurgical attending in case of an emergency, and immediate availability of the surgeon to be reached through a paging system and return to the OR.[14] All patients in the overlapping arm of this study were informed prior to surgery that their procedure would overlap with a separate procedure performed by the same surgeon.

Although the terms "overlapping" and "concurrent" have been used interchangeably in the literature, this study exclusively pertains to the practice of overlapping surgery as defined in this discussion. All overlapping surgeries were performed in accordance with the guidelines established by neurosurgery professional societies.

Limitations of the Study

One significant limitation of this study is that it was performed at a single high-volume institution with experienced functional neurosurgeons. High-volume centers typically utilize the practice of overlapping surgery more often; thus, the question of whether overlapping functional procedures are appropriate for smaller centers with less experienced surgeons remains.[15] Second, although the study had adequate power to detect a difference in overall complications at 1 year between the two groups, many of the CIs for the subgroup analysis odds ratios were rather large. These large CIs are due to a relatively low number of cases in these subgroups with a relatively low rate of complications. Future prospective studies should be designed to better elucidate potential differences between various factors included in our regression.

Senior Resident Coverage

The large CIs are particularly important to keep in mind when interpreting the increased risk associated with the involvement of senior residents in the case. One explanation is that the greater autonomy of senior residents and potentially greater complexity of cases may contribute to an increased rate of complications. Junior residents have more supervision from attending surgeons and may be involved with less complex cases with inherently lower risks of complications. However, this finding was not expected and should be carefully scrutinized. The 95% CIs include 1 and are exceedingly wide for both the univariate and multivariate regression (OR 3.5, 95% CI 0.81–15.16, p = 0.015, and OR 3.13, 95% CI 0.71–13.86, p = 0.02, respec-

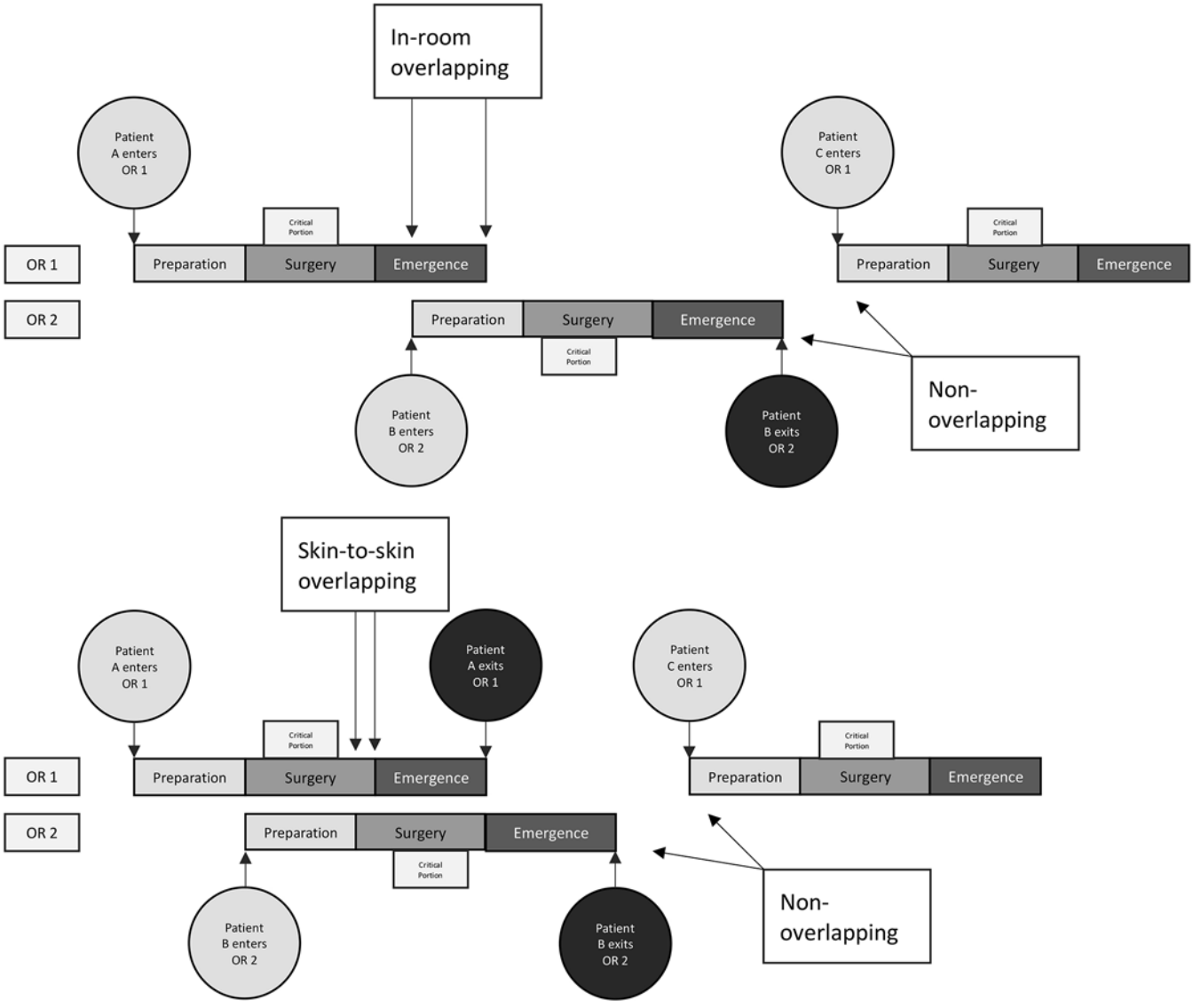

FIG. 1. Upper: Diagram showing two ORs with a depiction of two in-room overlapping procedures compared with completely nonoverlapping procedures. In-room overlapping means that two patients are in two separate ORs managed by one attending, but it does not mean the portion of surgery overlaps between the two, as depicted by the emergence of patient A overlapping with the preparation of patient B. **Lower:** Diagram showing two ORs with a depiction of two skin-to-skin overlapping procedures compared with completely nonoverlapping procedures. Skin-to-skin overlapping means that the portion of surgery between two patients managed by one attending overlaps.

tively). Additional research should be conducted to investigate the complication risk associated with surgical staffing.

Conclusions

The ability to perform overlapping surgery is beneficial for both surgeons and patients. The practice of overlapping surgery supports case volume, which creates experience and expertise for practicing surgeons, as well as adequate training for residents and fellows. For patients, overlapping surgery can increase access by decreasing surgery wait times and increasing the total number of patients who can be treated by a specialty neurosurgeon.[16] Our study shows that the practice of overlapping functional and stereotactic neurosurgery is safe for overlapping procedures and carries no increased risk of complications within 1 year postoperatively compared with nonoverlapping procedures. Overlapping procedures do not have longer OR times compared with nonoverlapping cases. Proper protocol including patient and case selection, appropriate OR staffing, and informed consent are vital to maintaining the safety and feasibility of this important practice and to ensuring optimal outcomes.

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Disclosures

Dr. Willie reports receiving honoraria from Medtronic, ClearPoint Neuro, and NeuroPace, and being a consultant to AiM Medical Robotics. Dr. Gross reports being a consultant to Medtronic, Boston Scientific, NeuroPace, Abbott Labs, Voyager Therapeutics, NeuroOne, Bluerock Therapeutics, and Aspen, and having direct stock ownership in Nia Therapeutics.

Author Contributions

Conception and design: Greven, Malcolm. Acquisition of data: Greven, Douglas, Nakirikanti, Malcolm, Campbell, Laxpati, Lamanna, Bray, Howard. Analysis and interpretation of data: Greven, Easley. Drafting the article: Greven. Critically revising the article: Greven, Douglas, Nakirikanti, Malcolm, Laxpati, Boulis, Gross. Reviewed submitted version of manuscript: Greven, Boulis, Gross. Approved the final version of the manuscript on behalf of all authors: Greven. Statistical analysis: Greven, Easley. Administrative/technical/material support: Greven. Study supervision: Greven, Malcolm. Surgeon: Willie, Boulis, Gross.

Supplemental Information

Previous Presentations

This paper was previously presented as an oral presentation at the 2021 CNS Annual Meeting in Austin, Texas, October 16–20.

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