Analysis of an overlapping surgery policy change on costs in a high-volume neurosurgical department

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OBJECTIVE Overlapping surgery remains a controversial topic in the medical community. Although numerous studies have examined the safety profile of overlapping operations, there are few data on its financial impact. The authors assessed direct hospital costs associated with neurosurgical operations during periods before and after a more stringent overlapping surgery policy was implemented.

METHODS The authors retrospectively reviewed the records of nonemergency neurosurgical operations that took place during the periods from June 1, 2014, to October 31, 2014 (pre-policy change), and from June 1, 2016, to October 31, 2016 (post-policy change), by any of the 4 senior neurosurgeons authorized to perform overlapping cases during both periods. Cost data as well as demographic, surgical, and hospitalization-related variables were obtained from an institutional tool, the Value-Driven Outcomes database.

RESULTS A total of 625 hospitalizations met inclusion criteria for cost analysis; of these, 362 occurred prior to the policy change and 263 occurred after the change. All costs were reported as a proportion of the average total hospitalization cost for the entire cohort. There was no significant difference in mean total hospital costs between the prechange and postchange period (0.994 ± 1.237 vs 1.009 ± 0.994 , $p = 0.873$). On multivariate linear regression analysis, neither the policy change ($p = 0.582$) nor the use of overlapping surgery ($p = 0.273$) was significantly associated with higher total hospital costs.

CONCLUSIONS A more restrictive overlapping surgery policy was not associated with a reduction in the direct costs of hospitalization for neurosurgical procedures.

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KEYWORDS overlapping surgery; costs; neurosurgery; value-driven outcomes

OVERLAPPING surgery, in which one surgeon oversees two procedures, with critical portions of each operation occurring at different times but with some overlap of noncritical portions,^{3,4} remains a controversial topic within the medical community. When the use of overlapping surgery entered the spotlight in late 2015,¹ there was little peer-reviewed literature on the subject. In the years since, several studies in a variety of surgical specialties have investigated the topic, with a focus on the safety of the practice.^{7,13,18,20} Although patient safety is and undoubtedly should be the primary concern of the overlapping surgery debate, some observers, including members

of a US Senate Finance Committee investigation, have raised concerns regarding the cost-effectiveness of the practice as well.²¹ Data on the costs related to overlapping procedures are scant, with only a single study published to date examining this association in spine surgeries.²²

Because of the paucity of information on this important topic, we sought to investigate the influence of overlapping surgery on hospital costs across a broad array of neurosurgical procedures. Our center is uniquely situated for this investigation for two reasons. In 2015, in the face of the controversy surrounding overlapping surgery, our institution implemented more stringent guidelines regard-

ABBREVIATIONS ASA = American Society of Anesthesiologists; VDO = Value-Driven Outcomes.

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ing the scheduling of overlapping cases, which significantly reduced their incidence. Furthermore, our institution maintains an institutional tool, the Value-Driven Outcomes (VDO) tool, which was developed for value-based healthcare analysis and evaluation of costs.¹⁴ Using the VDO, we analyzed total hospital costs before and after this policy change. Several possibilities for increased costs during overlapping surgery could include inefficient operating room utilization, longer operative times, increased complications resulting in a greater length of stay, and less efficient surgical equipment utilization. However, we hypothesized that overlapping surgery would not be associated with higher total hospital costs and that the policy change would not result in any cost reduction.

Methods

Approval was obtained from the institutional review board prior to data collection. The data collection methods for this study were previously published.⁹ The pre-policy change period extended from June 1, 2014, to October 31, 2014, and the post-policy change period lasted from June 1, 2016, to October 31, 2016. The full pre- and postchange policies can be found in our prior publication,⁹ but the most substantive modifications were 1) a new rule mandating that an overlapping case could not be initiated until after the completion of all critical portions of the first case, and 2) another rule dictating that the attending physician could not return to the first case after beginning a second (barring unforeseen circumstances). We dichotomized all neurosurgical cases involving patients 10 years and older that were performed by any of 4 neurosurgeons at our institution who were authorized to run overlapping surgery during both timeframes into overlapping and nonoverlapping for both periods. An overlapping case was defined as any case where 2 patients under the care of a single attending surgeon were under anesthesia at the same time for any period. For this study, emergency cases were excluded from our analysis because they were almost exclusively nonoverlapping and because of the high rate of adverse events due to the critical condition of the patient. Emergency operations were defined as cases begun less than 24 hours after being added to the schedule, because of the life-threatening nature of the condition being treated.

In addition to the data previously described, total hospital cost data, excluding physician fees, were obtained from the VDO. Cost was further divided into 5 broad categories: facility fees including operating room costs, pharmacy costs, supply and implant costs, imaging costs, and laboratory costs. Because of the proprietary nature of VDO data, actual dollar values are embargoed. All financial data in the study are reported as a proportion of average total hospital cost for all admissions in the cohort. Cases in which VDO data were unavailable were excluded, as were emergency cases or cases involving surgeries performed during the weekend and those involving patients younger than 10 years. Cases in which multiple surgeries were performed during the same hospitalization were only counted once; the overlapping status for these cases was based on the operation that occurred earliest during the hospitalization, although complications during the entire hospitalization

were taken into account, as were costs for all surgical procedures performed during these admissions. All 2014 cost values were adjusted for medical inflation over the study period at a rate of 6.52% based on US Bureau of Labor Statistics data (<https://www.bls.gov/cpi/>).

Statistical Analysis

Our study focused on analysis of cost-related data. For our univariate analysis, we utilized the Student t-test, 1-way ANOVA, or a Pearson bivariate cross-correlation analysis. Individual cost categories were analyzed with relation to both the policy change and overlap status. Total hospital cost was further analyzed in relation to all collected variables of interest. We also performed a multiple linear regression analysis of total hospital costs. Variables included in the linear regression model were those with $p < 0.2$ on univariate analysis. The length-of-stay variable was excluded because of its direct influence on cost and its high correlation with total hospital costs in our analysis. For all analyses, $p < 0.05$ was considered statistically significant. All statistical analysis was performed using IBM SPSS version 25.0 (IBM Corp).

Results

Patient Cohort

Of 695 cases performed by the 4 neurosurgeons during the study period, 625 (89.9%) met the criteria for inclusion. Twenty-three cases were excluded because they were classified as emergency, 16 cases occurred on a weekend, 2 cases were excluded because the patient was younger than 10 years at the time of surgery, and 1 elective case was excluded because it overlapped with an emergency case. Twenty-two additional cases were excluded because they were performed during the same hospitalization as another case. VDO data for 6 cases were unavailable, and these cases were excluded as well. Three hundred sixty-two admissions occurred prior to the overlapping surgery policy change (57.9%), and 263 occurred after the policy change (42.1%).

Univariate Analysis

The incidence of overlapping surgery decreased significantly after the policy change (pre-policy change 46.7% vs post-policy change 27.4%, $p < 0.001$; Table 1), but other variables such as case type did not change ($p = 0.644$). Overlapping surgery was not associated with any significant difference in any of the 5 individual cost categories (Table 2). After the policy change, laboratory costs were significantly increased ($p < 0.001$), but no other cost categories were significantly affected (Table 3). Complications were significantly associated with higher mean hospital costs, both overall ($p < 0.001$) and serious ($p < 0.001$) complications (Table 4). Patients who experienced higher-grade complications (defined as those having grade II or higher based on our previously described scale⁷) also incurred significantly higher hospital costs ($p < 0.001$). Costs for hospitalizations associated with urgent surgery were higher than those associated with elective surgery ($p < 0.001$).

Patients with preoperative tobacco use had significantly

TABLE 1. Univariate analysis of policy change

Variable	Pre-Policy Change (n = 362)	Post-Policy Change (n = 263)	p Value
Age, yrs $\pm$ SD	53.7 $\pm$ 16.2	49.1 $\pm$ 17.6	0.001
Male sex	182 (50.3)	105 (39.9)	0.010
Race/ethnicity			0.646
Caucasian	324 (89.5)	226 (85.9)	
Hispanic/Latino	19 (5.2)	17 (6.5)	
African American	1 (0.3)	2 (0.8)	
Asian	4 (1.1)	3 (1.1)	
American Indian	3 (0.8)	2 (0.8)	
Hawaiian/Pacific Islander	4 (1.1)	2 (0.8)	
Other/unknown	7 (1.9)	11 (4.2)	
BMI $\pm$ SD	28.6 $\pm$ 6.8	28.7 $\pm$ 6.9	0.902
Insurance type			0.031
Private	195 (53.9)	153 (58.2)	
Medicaid/self-pay	28 (7.7)	32 (12.2)	
Medicare	139 (38.4)	78 (29.7)	
ASA class			<0.001
I or II	166 (45.9)	152 (57.8)	
III	176 (48.6)	86 (32.7)	
IV or V	20 (5.5)	25 (9.5)	
Tobacco use	38 (10.5)	28 (10.6)	0.952
Alcohol use	119 (32.9)	97 (36.9)	0.298
Illicit drug use	21 (5.8)	17 (6.5)	0.732
Corticosteroid use	55 (15.2)	38 (14.4)	0.796
Cardiovascular comorbidity	56 (15.5)	35 (13.3)	0.449
Pulmonary comorbidity	116 (32.0)	88 (33.5)	0.709
Hepatobiliary comorbidity	14 (3.9)	6 (2.3)	0.266
Renal comorbidity	6 (1.7)	8 (3.0)	0.248
Neurological comorbidity	60 (16.6)	24 (9.1)	0.007
Oncological comorbidity	44 (12.2)	12 (4.6)	0.001
Diabetes	38 (10.5)	31 (11.8)	0.611
Hypertension	131 (36.2)	82 (31.2)	0.192
Surgery category			0.644
Craniotomy for tumor, simple	59 (16.3)	39 (14.8)	
Craniotomy for tumor, complex	17 (4.7)	18 (6.8)	
Craniotomy for aneurysm/vascular malformation	19 (5.2)	7 (2.7)	
Craniotomy for other	18 (5.0)	17 (6.5)	
Burr hole craniotomy	12 (3.3)	6 (2.3)	
Noninstrumented spine	44 (12.2)	36 (13.7)	
Instrumented spine	71 (19.6)	59 (22.4)	
Transnasal approach for tumor	31 (8.6)	20 (7.6)	
Shunt	42 (11.6)	32 (12.2)	
Miscellaneous	49 (13.5)	29 (11.0)	
Senior attending*	180 (49.7)	133 (50.6)	0.834
Overlapping surgery	169 (46.7)	72 (27.4)	<0.001

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TABLE 1. Univariate analysis of policy change

Variable	Pre-Policy Change (n = 362)	Post-Policy Change (n = 263)	p Value
Scheduling type			0.005
Elective	319 (88.1)	249 (94.7)	
Urgent	43 (11.9)	14 (5.3)	
Assistant training level			<0.001
PGY-1	5 (1.4)	5 (1.9)	
PGY-2	26 (7.2)	6 (2.3)	
PGY-3	4 (1.1)	15 (5.7)	
PGY-4	6 (1.7)	11 (4.2)	
PGY-5	88 (24.3)	34 (12.9)	
PGY-6	74 (20.4)	22 (8.4)	
PGY-7	114 (31.5)	80 (30.4)	
Fellow	45 (12.4)	90 (34.2)	
Op length, mins $\pm$ SD	277.3 $\pm$ 137.7	289.6 $\pm$ 128.8	0.261
Overlap time, mins $\pm$ SD	194.2 $\pm$ 102.5	156.8 $\pm$ 111.2	0.012
EBL, ml $\pm$ SD	199.1 $\pm$ 398.2	197.4 $\pm$ 280.0	0.952
LOS, days $\pm$ SD	4.3 $\pm$ 4.8	4.1 $\pm$ 3.9	0.654
Discharge destination			0.248
Home	251 (69.3)	196 (74.5)	
Home health	16 (4.4)	12 (4.6)	
Acute rehab	54 (14.9)	39 (14.8)	
SNF	28 (7.7)	8 (3.0)	
LTAC	8 (2.2)	6 (2.3)	
Death	3 (0.8)	2 (0.8)	
Other	2 (0.6)	0 (0)	
Intraop complications	21 (5.8)	14 (5.3)	0.798
Intraop complication grade			0.814
0	341 (94.2)	249 (94.7)	
I	17 (4.7)	13 (4.9)	
II	1 (0.3)	0 (0)	
III	2 (0.6)	1 (0.4)	
IV	1 (0.3)	0 (0)	
Postop complications	67 (18.5)	51 (19.4)	0.781
Postop complication grade			0.734
0	295 (81.5)	212 (80.6)	
I	36 (9.9)	29 (11.0)	
II	5 (1.4)	7 (2.7)	
III	24 (6.6)	14 (5.3)	
IV	2 (0.6)	1 (0.4)	
30-day complications	29 (8.0)	18 (6.8)	0.585
30-day complication grade			0.368
0	333 (92.0)	245 (93.2)	
I	12 (3.3)	3 (1.1)	
II	8 (2.2)	7 (2.7)	
III	8 (2.2)	8 (3.0)	
IV	1 (0.3)	0 (0)	
Any complication	97 (26.8)	72 (27.4)	0.872
Serious complication†	48 (13.3)	37 (14.1)	0.771

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TABLE 1. Univariate analysis of policy change

Variable	Pre-Policy Change (n = 362)	Post-Policy Change (n = 263)	p Value
Worst complication grade			0.862
0	265 (73.2)	191 (72.6)	
I	49 (13.5)	35 (13.3)	
II	16 (4.4)	13 (4.9)	
III	28 (7.7)	23 (8.7)	
IV	4 (1.1)	1 (0.4)	

EBL = estimated blood loss; LOS = length of stay; LTAC = long-term acute care facility; PGY = postgraduate year; rehab = rehabilitation; SNF = skilled nursing facility.

Values are presented as the number of cases (%) unless stated otherwise.

Boldface type indicates statistical significance.

* ≥ 20 years postresidency.

† Complications of grade II or higher.

higher hospital costs than those who did not ($p = 0.024$), although pulmonary comorbidities actually appeared to be associated with lower costs ($p = 0.036$). Patients in higher American Society of Anesthesiologists (ASA) classes incurred significantly higher hospital costs ($p < 0.001$), with ASA class V patients having a mean cost nearly 5 times higher than those in ASA class I. Surgery type was significantly associated with hospital cost ($p < 0.001$), with craniotomy for aneurysm/vascular malformation having the highest mean cost and noninstrumented spine surgery having the lowest mean cost. Discharge destination was also significantly associated with cost ($p < 0.001$), with home discharge having the lowest mean hospital costs and death having the highest. In our Pearson bivariate cross-correlation analysis, hospital cost was significantly correlated with longer operating room time (correlation coefficient 0.306, $p < 0.001$), higher intraoperative blood loss (correlation coefficient 0.263, $p < 0.001$), and length of stay (correlation coefficient 0.718, $p < 0.001$; Table 5).

Multivariate Analysis

In our multivariate linear regression model, the overlapping surgery policy change was not associated with any change in mean hospital costs in our cohort (Table 6; $B = 0.041$, 95% CI -0.106 to 0.189). The occurrence of any

TABLE 2. Univariate cost analysis of overlapping surgery

Cost Category	Mean Cost ± SD		p Value
	Nonoverlapping (n = 384)	Overlapping (n = 241)	
Facility	0.559 ± 0.701	0.496 ± 0.552	0.239
Pharmacy	0.122 ± 0.185	0.105 ± 0.136	0.226
Supply/implant	0.259 ± 0.369	0.253 ± 0.353	0.829
Imaging	0.026 ± 0.061	0.023 ± 0.072	0.637
Lab	0.073 ± 0.134	0.061 ± 0.168	0.302

TABLE 3. Univariate cost analysis of policy implementation

Cost Category	Mean Cost ± SD		p Value
	Pre-Policy Change (n = 362)	Post-Policy Change (n = 263)	
Facility	0.542 ± 0.723	0.524 ± 0.527	0.737
Pharmacy	0.112 ± 0.181	0.120 ± 0.147	0.577
Supply/implant	0.267 ± 0.378	0.242 ± 0.341	0.396
Imaging	0.026 ± 0.082	0.023 ± 0.032	0.522
Lab	0.046 ± 0.148	0.099 ± 0.142	<0.001

Boldface type indicates statistical significance.

complication during the hospitalization was associated with a significantly higher total hospital cost ($B = 0.321$, 95% CI 0.142 to 0.500), as was a surgery that was categorized as urgent during the hospitalization ($B = 0.385$, 95% CI 0.136 to 0.635). Tobacco use remained significantly associated with higher costs in our regression model ($B = 0.232$, 95% CI 0.011 to 0.453), whereas preoperative steroid use was associated with lower cost ($B = -0.239$, 95% CI -0.437 to -0.040). Compared with the reference of instrumented spine surgery, craniotomy for simple tumor ($B = -0.463$, 95% CI -0.698 to -0.228), craniotomy for complex tumor ($B = -0.447$, 95% CI -0.799 to -0.095), craniotomy for other ($B = -0.493$, 95% CI -0.822 to -0.164), and noninstrumented spine surgery ($B = -0.514$, 95% CI -0.770 to -0.258) were all associated with lower hospital costs. Compared with discharge home, all other discharge destinations apart from “other” were associated with higher costs (all $p < 0.05$). Finally, compared with a reference ASA class of II, ASA classes of III ($B = 0.172$, 95% CI 0.015–0.330) and IV ($B = 0.626$, 95% CI 0.314 to 0.939) were associated with higher costs.

Discussion

A number of studies have examined the association of overlapping surgery with adverse events,^{7,13,18,20} and although the vast majority of these have found no association between the practice and increased complication rate, a number of centers, including our own, have adjusted their policies in response to the increasing controversy. Our study represents the first analysis of costs related to overlapping surgery in a broad neurosurgical case mix and the first examining the influence of a more restrictive policy on costs.

Our results suggest that a more stringent overlapping surgery policy did not lead to cost savings in our cohort, and overlapping surgery was not associated with higher or lower costs in and of itself. The variables that did appear to lead to higher hospitalization costs were largely unsurprising—complications,^{5,12} emergency surgery,¹¹ operating room time,¹⁵ surgery type,⁶ inability to discharge home,¹⁷ higher ASA class,¹⁹ and tobacco use^{10,16}—and have all previously been shown to be significantly associated with hospital costs. Our finding that preoperative steroid use was associated with lower costs was somewhat surprising, although some evidence suggests that such use may reduce length of stay in patients undergoing crani-

TABLE 4. Analysis of total hospital costs

Variable (no. of cases)	Mean Cost $\pm$ SD	p Value
Policy status		0.873
Before change (362)	0.994 $\pm$ 1.237	
After change (263)	1.009 $\pm$ 0.994	
Complication		<0.001
No (456)	0.735 $\pm$ 0.741	
Yes (169)	1.716 $\pm$ 1.623	
Serious complication (grade $\geq$ II)		<0.001
No (540)	0.853 $\pm$ 0.870	
Yes (85)	1.937 $\pm$ 1.942	
Maximum complication grade		<0.001
None (456)	0.735 $\pm$ 0.741	
I (84)	1.493 $\pm$ 1.189	
II (29)	1.451 $\pm$ 2.235	
III (51)	2.053 $\pm$ 1.676	
IV (5)	3.563 $\pm$ 1.980	
30-day readmission		0.243
No (578)	0.985 $\pm$ 1.139	
Yes (47)	1.187 $\pm$ 1.144	
Intraop complication		<0.001
No (590)	0.925 $\pm$ 1.052	
Yes (35)	2.262 $\pm$ 1.719	
Postop complication		<0.001
No (507)	0.766 $\pm$ 0.765	
Yes (118)	2.007 $\pm$ 1.772	
Attending PGYs in practice		0.534
<20 (312)	0.972 $\pm$ 1.033	
$\geq$ 20 (313)	1.028 $\pm$ 1.239	
Surgery urgency		<0.001
Elective (568)	0.943 $\pm$ 1.011	
Urgent (57)	1.570 $\pm$ 1.940	
Assistant level of training		
PGY 1–6 (296)	0.932 $\pm$ 1.108	0.157
PGY 7 or fellow (329)	1.061 $\pm$ 1.166	
Patient sex		0.830
Male (287)	1.011 $\pm$ 1.159	
Female (338)	0.991 $\pm$ 1.126	
Overlap status		0.282
Nonoverlapping (384)	1.039 $\pm$ 1.215	
Overlapping (241)	0.938 $\pm$ 1.009	
Tobacco use		0.024
No (559)	0.965 $\pm$ 1.049	
Yes (66)	1.300 $\pm$ 1.712	
Alcohol use		0.368
No (409)	0.970 $\pm$ 1.118	
Yes (216)	1.057 $\pm$ 1.182	
Illicit drug use		0.705
No (587)	0.996 $\pm$ 1.128	
Yes (38)	1.068 $\pm$ 1.335	

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TABLE 4. Analysis of total hospital costs

Variable (no. of cases)	Mean Cost $\pm$ SD	p Value
Preop corticosteroid use		0.078
No (532)	1.034 $\pm$ 1.206	
Yes (93)	0.808 $\pm$ 0.618	
Cardiovascular comorbidity		0.380
No (534)	0.984 $\pm$ 1.128	
Yes (91)	1.097 $\pm$ 1.208	
Pulmonary comorbidity		0.036
No (421)	1.067 $\pm$ 1.227	
Yes (204)	0.863 $\pm$ 0.924	
Neurological comorbidity		0.383
No (541)	0.984 $\pm$ 1.123	
Yes (84)	1.101 $\pm$ 1.249	
Hepatobiliary comorbidity		0.874
No (605)	0.999 $\pm$ 1.147	
Yes (20)	1.040 $\pm$ 0.928	
Renal comorbidity		0.872
No (611)	1.001 $\pm$ 1.146	
Yes (14)	0.951 $\pm$ 0.867	
Oncological comorbidity		0.288
No (569)	0.985 $\pm$ 1.104	
Yes (56)	1.155 $\pm$ 1.460	
Diabetes		0.156
No (556)	0.977 $\pm$ 1.108	
Yes (69)	1.184 $\pm$ 1.364	
Hypertension		0.079
No (412)	0.942 $\pm$ 1.035	
Yes (213)	1.111 $\pm$ 1.315	
Surgery day of week		0.642
Monday (183)	0.903 $\pm$ 1.105	
Tuesday (68)	0.997 $\pm$ 1.249	
Wednesday (48)	1.094 $\pm$ 1.071	
Thursday (182)	1.003 $\pm$ 1.131	
Friday (144)	1.089 $\pm$ 1.269	
Surgery type		<0.001
Craniotomy for tumor, simple (98)	0.977 $\pm$ 0.977	
Craniotomy for tumor, complex (35)	1.356 $\pm$ 1.378	
Craniotomy for aneurysm/vascular malformation (26)	2.146 $\pm$ 2.476	
Craniotomy for other (35)	0.810 $\pm$ 0.715	
Burr hole craniotomy (18)	1.173 $\pm$ 1.281	
Noninstrumented spine (80)	0.323 $\pm$ 0.207	
Instrumented spine (130)	1.373 $\pm$ 1.126	
Transnasal approach for tumor (51)	0.573 $\pm$ 0.367	
Shunt procedure (74)	0.783 $\pm$ 0.955	
Miscellaneous (78)	1.092 $\pm$ 1.176	

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TABLE 4. Analysis of total hospital costs

Variable (no. of cases)	Mean Cost $\pm$ SD	p Value
Attending		0.627
1 (203)	0.974 $\pm$ 1.094	
2 (102)	0.955 $\pm$ 1.048	
3 (110)	1.129 $\pm$ 1.469	
4 (210)	0.979 $\pm$ 1.028	
Discharge destination		<0.001
Home (447)	0.661 $\pm$ 0.602	
Home health (28)	1.260 $\pm$ 1.154	
Rehab (93)	1.798 $\pm$ 1.449	
SNF (36)	1.555 $\pm$ 1.742	
LTAC (14)	3.523 $\pm$ 1.958	
Death (5)	3.898 $\pm$ 1.546	
Other (2)	1.134 $\pm$ 0.662	
Insurance type		0.671
Private (348)	0.982 $\pm$ 1.047	
Medicaid/self-pay (60)	1.124 $\pm$ 1.761	
Medicare (217)	0.995 $\pm$ 1.069	
Race/ethnicity		0.212
Caucasian (550)	0.971 $\pm$ 1.132	
Hispanic/Latino (36)	1.054 $\pm$ 1.007	
African American (3)	1.597 $\pm$ 1.819	
Asian (7)	0.743 $\pm$ 0.234	
American Indian (5)	1.794 $\pm$ 1.107	
Hawaiian/Pacific Islander (6)	1.824 $\pm$ 2.704	
Other/unknown (18)	1.293 $\pm$ 0.860	
ASA classification		<0.001
I (31)	0.635 $\pm$ 0.690	
II (287)	0.720 $\pm$ 0.640	
III (262)	1.126 $\pm$ 1.177	
IV (42)	2.240 $\pm$ 2.174	
V (3)	3.186 $\pm$ 2.694	

ANOVA and the Student t-test were used for comparisons. Boldface type indicates statistical significance.

otomy for tumor, which may partially explain this association.² The finding that laboratory costs for our cohort were significantly higher after the policy change was also

unexpected, although we believe that this is more likely related to the introduction of new technologies to our hospital system (e.g., rotational thromboelastometry).⁸ Case mix prior to the policy change and after the policy change was not significantly different in our cohort, as previously reported.⁹ The total number of cases performed before the policy change (378) was more than that performed after the change (275), and thus the sum total of direct hospital costs after the policy change was only 73.4% of costs before the policy change. The more restrictive policy did appear effective in limiting overlapping surgery, as the rate of overlapping cases declined from 46% prechange to 26.9% postchange.⁹

Our study has several limitations. As with any retrospective study, ours is vulnerable to confounding. Our study was limited to a single center and may not be generalizable to other practices. The inability to release dollar values makes our data relatively harder to interpret, although the uniform transformation of our values throughout the study should ensure that our findings were not significantly affected. Finally, our study only examines direct costs, and we cannot therefore make any conclusions regarding the effect of this policy change on indirect costs associated with care.

Despite these limitations, we believe that our data accurately indicate that the policy changes aimed at restricting overlapping surgery at our center have not resulted in any cost savings. In fact, our results implicate complications as a major cost driver for neurosurgical hospitalizations, and the fact that overlapping surgery was not associated with higher costs further supports the conclusion from other studies that overlapping surgery does not result in higher complication rates. Furthermore, less-efficient resource utilization that has been predicted to occur with overlapping surgery, which could result in longer operating room times or lengths of stay, was not observed in this analysis.

Conclusions

In our cohort, a more restrictive overlapping surgery policy was not associated with any significant reductions in hospital costs. Additional investigation is needed to further characterize whether limiting overlapping surgery has any economic healthcare benefits.

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TABLE 5. Pearson bivariate cross-correlation of continuous variables with total hospital costs

Variable	Total Hospital Costs	OR Time	Patient Age	BMI	Intraop EBL	LOS
Total hospital costs	1	0.306*	-0.008	-0.014	0.263*	0.718*
OR time		1	0.005	-0.006	0.552*	0.385*
Patient age			1	-0.032	0.010	0.019
BMI				1	0.015	-0.035
Intraop EBL					1	0.257*
LOS						1

OR = operating room.

* $p < 0.001$.

TABLE 6. Multivariate linear regression of factors affecting total hospital cost

Variable	B (SE)	95% CI	p Value
Post-policy change	0.041 (0.075)	−0.106 to 0.189	0.582
Any complication	0.321 (0.091)	0.142 to 0.500	<0.001
Urgent surgery	0.385 (0.127)	0.136 to 0.635	0.002
Chief resident/fellow assistant	0.002 (0.076)	−0.148 to 0.151	0.981
Overlapping surgery	−0.080 (0.073)	−0.223 to 0.063	0.273
Tobacco use	0.232 (0.112)	0.011 to 0.453	0.040
Preop steroid use	−0.239 (0.101)	−0.437 to −0.040	0.019
Pulmonary comorbidity	−0.140 (0.077)	−0.290 to 0.011	0.068
Diabetes	−0.027 (0.118)	−0.258 to 0.205	0.820
Hypertension	0.033 (0.079)	−0.121 to 0.188	0.673
OR time, mins	0.002 (0.000)	0.001 to 0.003	<0.001
Intraop EBL (ml)	0.000 (0.000)	0.000 to 0.000	0.067
Surgery type			
Instrumented spine	Ref	Ref	
Craniotomy for tumor, simple	−0.463 (0.120)	−0.698 to −0.228	<0.001
Craniotomy for tumor, complex	−0.447 (0.179)	−0.799 to −0.095	0.013
Craniotomy for aneurysm/vascular malformation	0.226 (0.197)	−0.162 to −0.614	0.252
Craniotomy for other	−0.493 (0.167)	−0.822 to −0.164	0.003
Burr hole craniotomy	−0.386 (0.233)	−0.844 to 0.071	0.098
Noninstrumented spine	−0.514 (0.130)	−0.770 to −0.258	<0.001
Transnasal approach for tumor	−0.293 (0.156)	−0.600 to 0.013	0.060
Shunt procedure	−0.220 (0.141)	−0.496 to 0.056	0.118
Miscellaneous	−0.117 (0.143)	−0.398 to 0.164	0.413
Discharge destination			
Home	Ref	Ref	
Home health	0.380 (0.171)	0.044 to 0.716	0.027
Rehab	0.643 (0.113)	0.421 to 0.866	<0.001
SNF	0.500 (0.157)	0.192 to 0.809	0.002
LTAC	2.350 (0.256)	1.849 to 2.852	<0.001
Death	1.758 (0.429)	0.916 to 2.600	<0.001
Other	−0.107 (0.611)	−1.308 to 1.093	0.861
ASA classification			
I	0.042 (0.165)	−0.282 to 0.366	0.800
II	Ref	Ref	
III	0.172 (0.080)	0.015 to 0.330	0.031
IV	0.626 (0.159)	0.314 to 0.939	<0.001
V	0.735 (0.534)	−0.314 to 1.784	0.169

SE = standard error.

Boldface type indicates statistical significance.

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Conception and design: Schmidt, Guan, Karsy. Acquisition of data: Guan. Analysis and interpretation of data: Guan. Drafting the article: Guan, Karsy. Critically revising the article: Schmidt, Guan, Karsy, Brock, Couldwell, Kestle, Jensen, Bisson. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Schmidt. Statistical analysis: Dailey.

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