Perioperative Coronavirus Disease 2019 (COVID-19) Incidence and Outcomes in Neurosurgical Patients at Two Tertiary Care Centers in Washington, DC, During a Pandemic: A 6-Month Follow-up

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■ OBJECTIVE: **Coronavirus disease 2019 (COVID-19) continues to affect all aspects of health care delivery, and neurosurgical practices are not immune to its impact. We aimed to evaluate neurosurgical practice patterns as well as the perioperative incidence of COVID-19 in neurosurgical patients and their outcomes.**

■ METHODS: **A retrospective review of neurosurgical and neurointerventional cases at 2 tertiary centers during the first 3 months of the first peak of COVID-19 pandemic (March 8 to June 8) as well as following 3 months (post-peak pandemic; June 9 to September 9) was performed. Baseline characteristics, perioperative COVID-19 test results, modified Medically Necessary, Time-Sensitive (mMeNTS) score, and outcome measures were compared between COVID-19—positive and—negative patients through bivariate and multivariate analysis.**

■ RESULTS: **In total, 652 neurosurgical and 217 neurointerventional cases were performed during post-peak pandemic period. Cervical spine, lumbar spine, functional/pain, cranioplasty, and cerebral angiogram cases were significantly increased in the postpandemic period. There was a 2.9% (35/1197) positivity rate for COVID-19 testing overall and 3.6% (13/363) positivity rate postoperatively. Age, mMeNTS score, complications, length of stay, case acuity, American Society of Anesthesiologists status, and disposition were significantly different between COVID-19—positive and—negative patients.**

■ CONCLUSIONS: **A significant increase in elective case volume during the post-peak pandemic period is feasible with low and acceptable incidence of COVID-19 in neurosurgical patients. COVID-19—positive patients were younger, less likely to undergo elective procedures, had increased length of stay, had more complications, and were discharged to a location other than home. The mMeNTS score plays a role in decision-making for scheduling elective cases.**

INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic continues to affect every aspect of society, especially health care systems, across the globe. As of November 17, 2020, there have been more than 53.7 million cases with more than 1.3 million deaths, with the United States accounting for 19% of cases and deaths worldwide.[1] As the pandemic continued to surge, elective cases were canceled mid-March.[2] In line with phase 1 of reopening, on May 31, 2020, the District of Columbia (DC) Department of Health issued guidance for elective cases to resume.[3] During the first 3 months in Washington, DC, an analysis of neurosurgical case volumes and COVID-19 incidence was done at 2 tertiary medical centers, providing an objective measure of impact and incidence.[4]

As the pandemic continues to impact health care delivery with a daily increase of about 60,000 confirmed cases in the United States

Key words
- COVID-19
- Neurointerventional
- Neurosurgery
- Nosocomial infection
- Pandemic response
- SARS-CoV-2

Abbreviations and Acronyms
CI: Confidence interval
COVID-19: Coronavirus disease 2019
DC: District of Columbia
LOS: Length of stay
mMeNTS: modified Medically Necessary, Time-Sensitive
OR: Odds ratio

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alone,[5] and elective cases resumed in most centers, many hospital systems continue to find difficulty in evaluating the risk of nosocomial infection among surgical patients and deploying enough resources efficiently to support the acute medical needs of patients. There have been estimates of the financial impact and lasting effects in patient backlog for elective cases.[6,7] In addition, within neurosurgery, many surgical procedures are time-sensitive yet not necessarily nonelective—patients treated sooner may benefit most from surgical intervention.[8,9] Hence, weighing the risks and benefits of continuing with a full-time elective practice is of utmost importance, especially amidst predictions of a second and third "wave" projected to occur in the next few months.[10] These risks and benefits remain to be clearly elucidated, as there is a lack of literature addressing perioperative incidence and nosocomial infection risk of COVID-19.

In this study, we aimed to study patients and neurosurgical practices at 2 tertiary hospitals in Washington, DC, as a 3-month follow-up to our initial study. We compared the nosocomial incidence rates of COVID-19 among neurosurgical patients during the cancellation and resumption of elective cases. Furthermore, we evaluated assigned acuity and modified medically necessary, time-sensitive (mMeNTS) scores to determine the risk stratification of COVID-19 and outcomes among patients who underwent either neurosurgical or neurointerventional care. We hypothesized that there would be a small risk of COVID-19 positivity in lieu of a large elective practice, and that the mMeNTS score may help risk stratify these patients and help improve outcomes among neurosurgical patients.

METHODS

Study Design

We performed a retrospective analysis of all neurosurgical and neurointerventional procedures at both MedStar Washington Hospital Center and MedStar Georgetown University Hospital in Washington, DC, spanning 2 study periods: the first peak of pandemic period (March 8-June 8) and the post-peak pandemic period (June 9-September 9), which represents time period after the first peak. Elective cases were canceled between March 19 and May 31, 2020, within the peak pandemic period (**Figure 1**). Comparisons were made between the 2 study periods to evaluate effects of COVID-19 on neurosurgical practice patterns as well as patient COVID-19 incidence and outcomes. This study was approved by the institutional review boards at both respective institutions.

Data Variables and Subgroups

Our study included all adult patients undergoing neurosurgical and neurointerventional procedures during the study periods. Chart review was conducted through electronic medical records and operative records. Data were collected on the following

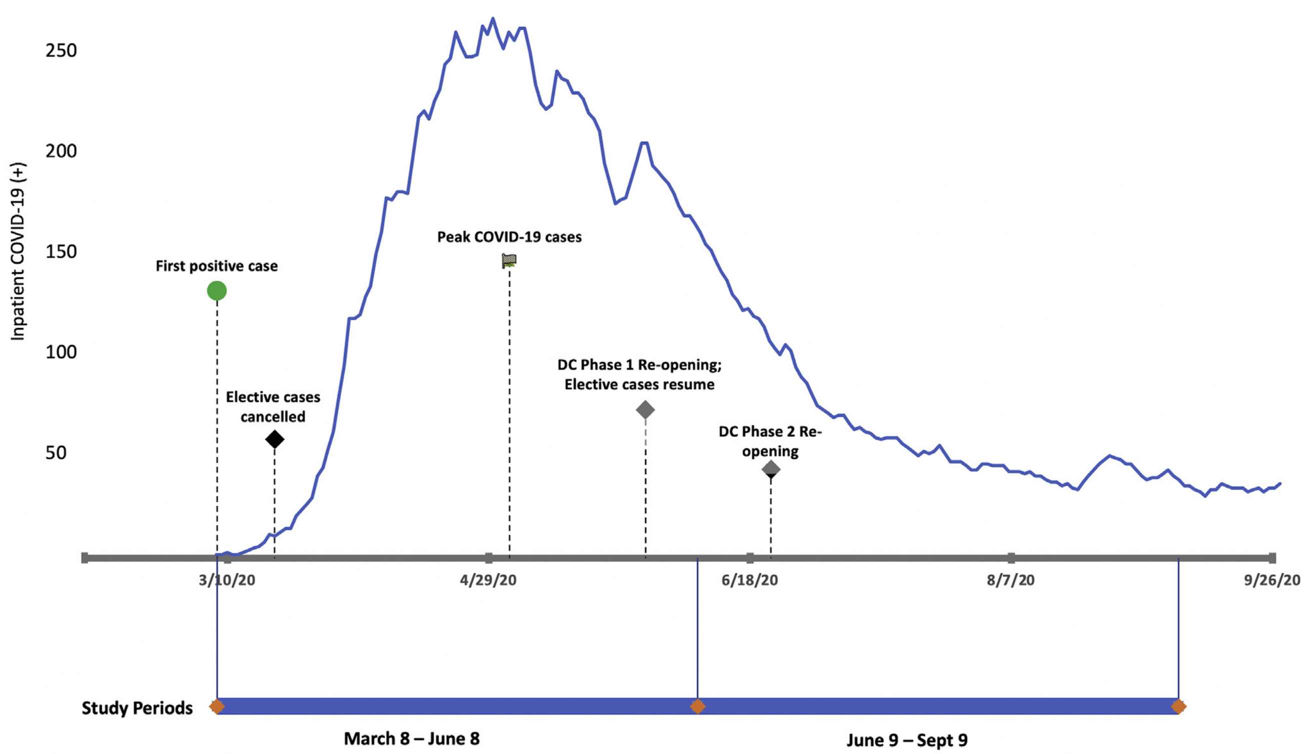

Figure 1. Timeline of coronavirus disease 2019 (COVID-19) pandemic with portrayal of study timeline starting March 8, 2020 (coinciding with the first COVID-19 diagnosis in Washington, DC) and divided into peak-pandemic period (March 8-June 8) and post-peak pandemic period (June 9-Sept 9). In-patient census of COVID-19—positive patients at 2 tertiary care centers in Washington, DC, shown as *line graph* with peak on April 30, 2020. Elective cases were cancelled starting March 18, 2020, and resumed for neurosurgery on June 1, 2020, along with Phase I of DC reopening.

baseline characteristics: age, sex, race, race/ethnicity, diagnosis, comorbidities, American Society of Anesthesiologists physical status class, case type, case assigned acuity, and assigned mMeNTS score as presented previously.[4] Outcomes data collected included postoperative complications, length of stay (LOS), discharge disposition, 30-day readmission, preoperative COVID-19 status, postoperative COVID-19 status at $\leq$1 month, and date of testing. All tests were completed via nasopharyngeal swab polymerase chain reaction testing.

Cases and patients between each study period were compared to evaluate differences in patient population and procedural practice patterns. In addition, patients who had a positive perioperative COVID-19 test were compared with those who tested negative to characterize differences in outcomes between COVID-19—positive and—negative patients.

Statistical Analysis

Continuous variables were summarized as means with standard deviations. *t* test/Wilcoxon rank sum tests were used to compare the difference between continuous variables depending on distribution. Categorical variables were aggregated as frequencies and percentages. χ^2 and Fisher exact tests were used to compare proportional differences of categorical variables between peak pandemic and post-peak pandemic case variables. Multivariable logistic regression analysis was used to analyze independent variables against COVID-19 status. All analyses were performed using Stata (version 16.0; StataCorp, College Station, Texas, USA). Statistical significance was defined as a *P* value of less than 0.05.

RESULTS

Neurosurgical Cases

In total, 405 operative neurosurgical cases for 386 patients were performed during the peak pandemic period and 652 cases for 610 patients were performed during the post-peak pandemic period. There was a 61.0% increase in case volume ($P = 0.0012$) during the post-peak period (Figure 2A). There were significantly greater proportion of lumbar spine (25.9% vs. 33.0%; $P = 0.0190$), functional/pain (5.7 vs. 9.0%; $P = 0.0451$), and cranioplasty procedures (0.0% vs. 2.9%; $P = 0.0001$) performed in the post-peak period. Elective cases made up a significantly larger proportion of cases in the post-peak period (30.4% vs. 73.3%; $P < 0.0001$). Mean mMeNTS score was lower in patients operated on in the post-peak period (8.2 vs. 7.5; $P < 0.0001$) (Table 1).

There was a significantly lower frequency of postoperative complications (19.0% vs. 12.6%; $P = 0.0059$) and more patients were discharged home (70.4% vs. 76.2%; $P = 0.0367$) during the post-peak period compared with peak pandemic period. There were no significant differences in LOS and 30-day readmissions between the patients of the 2 time periods (Table 1). A total of 26 (2.9%) cases were canceled due to a positive COVID-19 test (14/26) or due to patient's fear of COVID-19 contraction (12/26).

Neurointerventional Cases

A total of 121 neurointerventional cases for 112 patients were performed during the peak pandemic period and 217 cases for 180 patients were performed during the post-peak pandemic period. There was a 79.3% increase in case volume ($P = 0.0002$) during the post-peak period (Figure 2B). Similar to neurosurgical cases, mean mMeNTS score was lower in patients undergoing neurointerventional cases in the post-peak period (9.0 vs. 7.8; $P < 0.0001$) (Table 2). There was a significant difference in case types with a greater proportion of diagnostic cerebral angiograms (32.2% vs. 47.5%; $P = 0.0081$) performed in the post-peak period. There was a greater proportion of cases that were done electively in the post-peak period (13.2% vs. 31.3%; $P < 0.0001$) (Table 2).

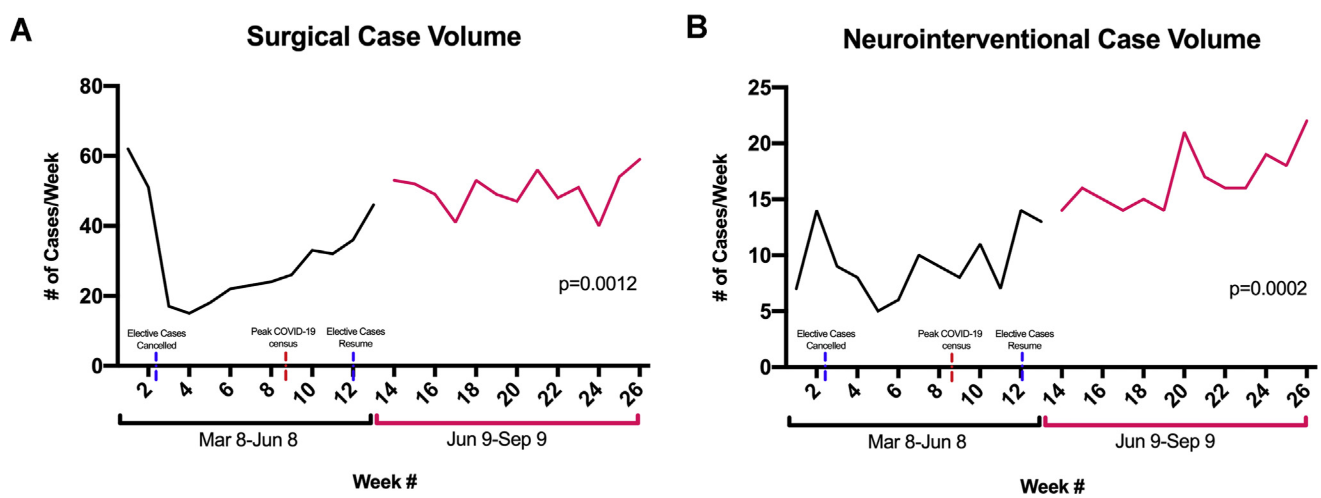

Figure 2. (**A**) Surgical operative case volume and (**B**) neurointerventional case volume compared between 2020 peak pandemic period to the following post-peak pandemic period. There was a significant increase in number of weekly case volumes for both surgical ($P = 0.0012$) and neurointerventional ($P = 0.0002$) cases.

Table 1. Baseline Characteristics and Outcomes of Patients Undergoing Neurosurgical Procedures During Peak Pandemic (March 8 to June 8) and Post-Peak Pandemic Period (June 9 to September 9)

	n (%)		
	March 8 to June 8	**June 9 to September 9**	***P* Value**
Total cases	405	652	0.0002*
Total patients	386	610	0.0002*
Mean age, years	57.1 ± 16.2	57.8 ± 14.2	0.4668
Male sex	207 (53.6)	300 (49.2)	0.1728
Preoperative tests	231 (57.0)	652 (100.0)	<0.0001*
Mean days tested preoperative	2.3 ± 3.1	2.7 ± 1.5	0.0367*
Preoperative negative	225 (97.4)	639 (98.0)	0.6004
Preoperative positive	6 (2.6)	13 (2.0)	
Postoperative tests	115 (28.4)	225 (34.5)	0.0422*
Mean days tested postoperative	11.6 ± 10.3	11.4 ± 8.7	0.7385
Postoperative negative	111 (96.5)	218 (96.9)	0.9999
Postoperative positive	4 (3.5)	7 (3.1)	
Case acuity			<0.0001*
Emergent	92 (22.7)	60 (9.2)	<0.0001*
Urgent	183 (45.2)	114 (17.5)	<0.0001*
Elective	123 (30.4)	478 (73.3)	<0.0001*
Case type			0.0005*
Spine—cervical/cervicothoracic	85 (21.0)	120 (18.4)	0.3370
Spine—thoracic	32 (7.9)	27 (4.1)	0.0526
Spine—lumbar/thoracolumbar	105 (25.9)	214 (33.0)	0.0191*
Craniotomy—tumor/abscess	53 (13.0)	73 (11.2)	0.3800
Craniotomy—vascular lesions	25 (6.2)	27 (4.1)	0.1454
Craniotomy—ICH/CVA/trauma	32 (7.9)	50 (7.7)	0.9062
Functional/pain	23 (5.7)	60 (9.0)	0.0451*
CSF diversion	20 (4.9)	25 (3.8)	0.4341
Endonasal/transsphenoidal	19 (4.7)	23 (3.5)	0.4182
Cranioplasty	0 (0.0)	19 (2.9)	0.0001*
Other	9 (2.2)	14 (2.1)	0.9999
Race/ethnicity			0.8544
White Non-Hispanic	203 (52.6)	301 (49.3)	0.3297
Black/African-American	139 (36.0)	236 (38.7)	0.4207
Hispanic	22 (5.7)	39 (6.4)	0.6866
Asian	9 (2.3)	16 (2.6)	0.8381
Other	13 (3.4)	18 (3.0)	0.7117
Comorbidities			0.9109
HTN	190 (49.2)	326 (53.4)	0.2162
DM	76 (19.7)	133 (21.8)	0.4724
CAD	28 (7.3)	66 (10.8)	0.0746
CKD/ESRD	20 (5.2)	44 (7.2)	0.2333
Malignancy	50 (13.0)	88 (14.4)	0.5724
COPD	11 (2.8)	24 (3.9)	0.4803
DVT/PE	20 (5.2)	35 (5.7)	0.7768
CVA/TIA	25 (6.5)	49 (8.0)	0.3877
Mean mMeNTS score	8.2 ± 1.6	7.5 ± 1.3	<0.0001*
Median ASA status [IQR]	3 [2–4]	3 [2–4]	0.0749
Mean LOS	8.9 ± 11.0	8.1 ± 12.2	0.2901
Complications	77 (19.0)	82 (12.6)	0.0059*
30-day readmission	32 (7.9)	64 (9.8)	0.3227
Disposition			0.2736
Home	285 (70.4)	497 (76.2)	0.0367*
Death/hospice	17 (4.2)	19 (2.9)	0.2965
Acute rehabilitation	68 (16.8)	89 (13.7)	0.1820
Skilled nursing facility	27 (6.7)	39 (6.0)	0.6955
Long-term care facility	8 (2.0)	8 (1.2)	0.4376

ICH, intracranial hemorrhage; CSF, cerebrospinal fluid; HTN, hypertension; DM, diabetes mellitus; CAD, coronary artery disease; CKD, chronic kidney disease; ESRD, end-stage renal disease; COPD, chronic obstructive pulmonary disease; DVT, deep venous thrombosis; PE, pulmonary embolism; CVA, cerebrovascular accident; TIA, transient ischemic attack; mMeNTS, modified Medically-Necessary, Time-Sensitive Procedures; ASA, American Society of Anesthesiologists; IQR, interquartile range; LOS, length of stay.
*Statistically significant.

There was a significantly lower frequency of postoperative complications (47.9% vs. 23.5%; $P < 0.0001$) and more patients were discharged home versus other settings (40.5% vs. 51.6%; $P = 0.0498$) compared with the peak phase of the pandemic. There were no significant differences in LOS and 30-day readmissions between the patients of the 2 time periods (Table 2).

Table 2. Baseline Characteristics and Outcomes of Patients Undergoing Neurointerventional Procedures During Peak Pandemic (March 8 to June 8) and Post-Peak Pandemic Period (June 9 to September 9)

	n (%)		
	March 8 to June 8	**June 9 to September 9**	***P* Value**
Total cases	121	217	0.0012*
Total patients	112	180	0.0009*
Mean age, years	61.3 ± 15.4	59.2 ± 14.7	0.2167
Male sex	65 (58.0)	83 (46.1)	0.0544
Preoperative tests	88 (72.7)	217 (100.0)	<0.0001*
Mean days tested preoperative	1.5 ± 2.3	1.9 ± 2.1	0.1057
Preoperative negative	81 (92.0)	208 (95.9)	0.2542
Preoperative positive	7 (8.0)	9 (4.1)	
Postoperative tests	64 (52.9)	138 (63.6)	0.0642
Mean days tested Postoperative	11.1 ± 8.8	9.6 ± 7.1	0.2293
Postoperative negative	63 (98.4)	132 (95.7)	0.4354
Postoperative positive	1 (1.6)	6 (4.3)	
Case acuity			<0.0001*
Emergent	70 (57.9)	78 (34.6)	0.0002*
Urgent	34 (28.1)	74 (34.1)	0.2754
Elective	16 (13.2)	65 (31.3)	0.0005*
Case type			0.0414*
Diagnostic cerebral	39 (32.2)	103 (47.5)	0.0081*
Embolization—aneurysm/AVM	21 (17.4)	31 (14.3)	0.3406
Embolization—tumor	6 (5.0)	9 (4.1)	0.5784
Embolization—MMA	11 (9.1)	17 (7.8)	0.8386
Stroke thrombectomy	29 (24.0)	30 (13.8)	0.1080
Vasospasm treatment	6 (5.0)	14 (6.5)	0.6403
Spine intervention	8 (6.6)	6 (2.8)	0.1514
Carotid stent	4 (3.3)	6 (2.8)	0.7496
Other	5 (4.1)	1 (0.5)	0.1025
Race/ethnicity			0.2516
White Non-Hispanic	58 (51.8)	72 (40.0)	0.0534
Black/African-American	45 (40.2)	81 (45.0)	0.4665
Hispanic	3 (2.7)	10 (5.6)	0.3825
Asian	2 (1.8)	7 (3.9)	0.4902
Other	4 (3.6)	9 (5.0)	0.5775
Comorbidities			0.7805
HTN	76 (67.9)	97 (54.0)	0.0567
DM	26 (23.2)	45 (25.0)	0.7294
CAD	15 (13.4)	13 (7.2)	0.0816
CKD/ESRD	12 (10.7)	14 (8.0)	0.4048
Malignancy	18 (16.1)	19 (11.0)	0.2054
COPD	8 (7.2)	10 (5.6)	0.6217
DVT/PE	5 (4.5)	6 (3.3)	0.7539
CVA/TIA	5 (4.5)	11 (6.0)	0.6083
Mean mMeNTS score	9.0 ± 1.8	7.8 ± 1.5	<0.0001*
Median ASA status [IQR]	3 [2—4]	3 [2—4]	0.9999
Mean LOS	13.5 ± 10.8	14.9 ± 13.3	0.3229
Complications	58 (47.9)	51 (23.5)	<0.0001*
30-day readmission	7 (5.8)	19 (8.8)	0.3979
Disposition			0.0896
Home	49 (40.5)	112 (51.6)	0.0498*
Acute rehabilitation	48 (39.7)	70 (32.3)	0.1910
Skilled nursing facility	12 (9.9)	10 (4.6)	0.0675
Long-term care facility	1 (0.8)	6 (2.8)	0.4287
Death/hospice	11 (9.1)	21 (9.7)	0.9999

AVM, arteriovenous malformation; MMA, middle meningeal artery; HTN, hypertension; DM, diabetes mellitus; CAD, coronary artery disease; CKD, chronic kidney disease; ESRD, end-stage renal disease; COPD, chronic obstructive pulmonary disease; DVT, deep venous thrombosis; PE, pulmonary embolism; CVA, cerebrovascular accident; TIA, transient ischemic attack; mMeNTS, modified Medically-Necessary, Time-Sensitive Procedures; ASA, American Society of Anesthesiologists; IQR, interquartile range; LOS, length of stay.
*Statistically significant.

Case Type

Cervical/cervicothoracic, lumbar/thoracolumbar, functional/pain and cranioplasty neurosurgical cases had the most significant increase in volume (Figure 3A). When dividing surgical cases into spine and cranial, total spine neurosurgical cases had a significant increase with an average of 17 spine cases/week during peak pandemic period versus 28 spine cases/week during the post-peak period ($P = 0.0101$). There was no significant increase in volume of cranial cases (11 cases/week vs. 14 cases/week; $P = 0.2353$) (Figure 3B). For the neurointerventional cases, the post-pandemic period saw a significant increase in diagnostic cerebral angiogram cases (164% increase; $P < 0.001$) compared with the peak period, while all other case type volumes did not significantly differ (Figure 3C).

COVID-19 Incidence

In the peak pandemic period, there were 18 of 334 (5.4%) patients who tested positive perioperatively. Of these patients, 13 were

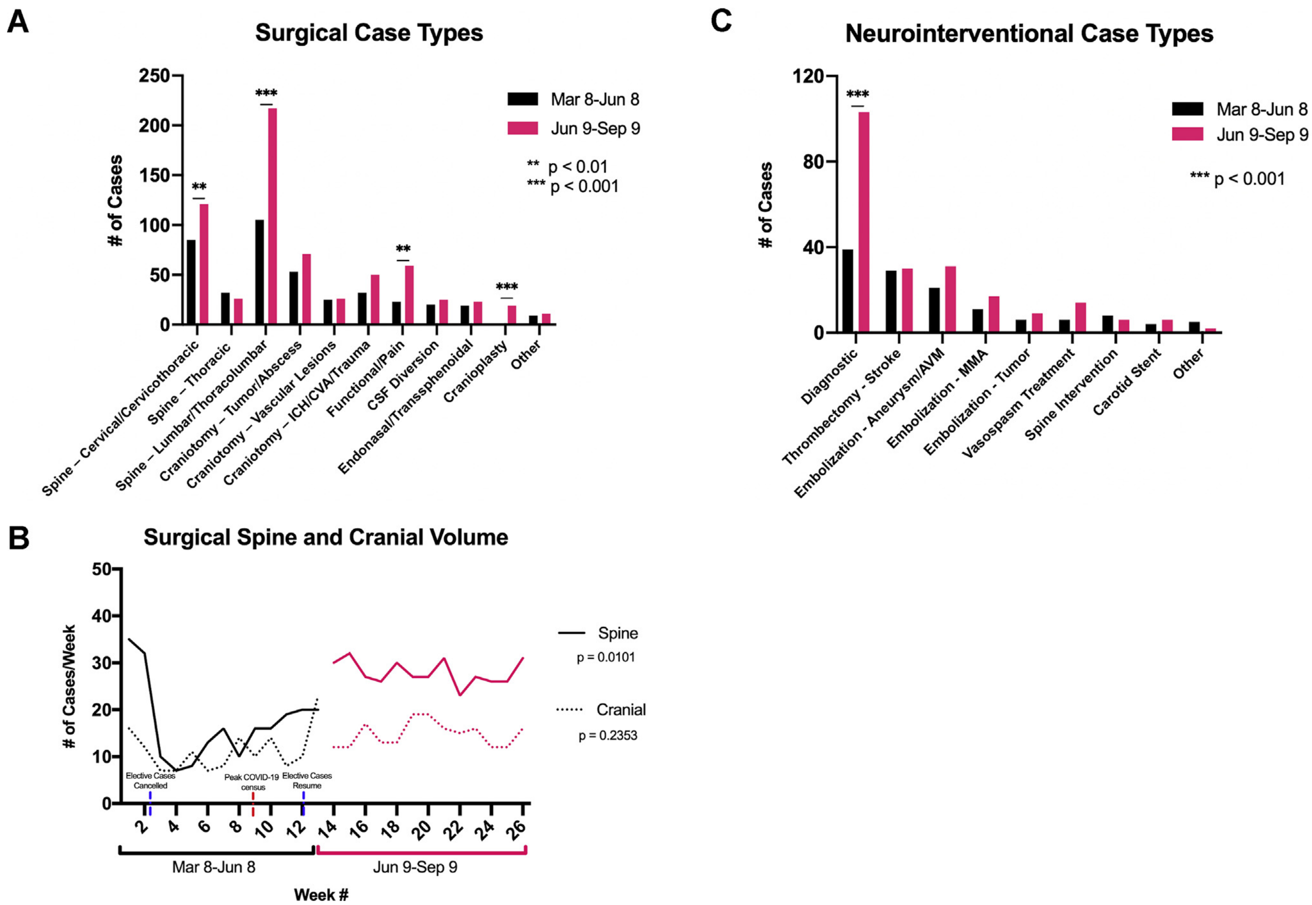

Figure 3. (**A**) Surgical case volume by case type comparing peak pandemic period with post-peak pandemic period. (**B**) Surgical cases over time during peak pandemic period and post-peak pandemic period divided into spinal (*solid lines*) and cranial (*dotted lines*) cases. (**C**) Neurointerventional case volume by case type comparing peak pandemic period with post-peak pandemic period.

positive preoperatively (13/180 patients tested; 7.2%), and 5 were positive postoperatively (5/154 patients tested; 3.2%). In the post-pandemic period, for both surgical and neurointerventional patients, there was a significant increase in preoperative COVID-19 testing with 100% of patients being tested before their procedure ($P < 0.0001$). There was also an increase in postoperative testing for the surgical patients (28.4% vs. 34.5%; $P = 0.0422$). There was an overall 2.9% (35/1,197) perioperative positive incidence for all perioperative tests performed (Table 3). Preoperative tests were conducted for a total of 869 cases and 2.5% (22/869) tested positive, significantly lower than the peak pandemic period ($P = 0.0014$). Thirteen patients (13/363 patients; 3.6%) tested positive postoperatively, not significantly different from the rate during the peak pandemic period. Two of these patients tested positive both pre- and postoperatively, meaning the percentage of new positive postoperative patients was 3.0% (11/363). Neurointerventional patients had a greater rate of positive testing than neurosurgical patients (6.9% vs. 3.1%; $P = 0.0165$) (Table 3).

COVID-19—Positive Patients

Compared with patients testing negative in the perioperative period, those testing positive for COVID-19 were on average younger (51.1 vs. 58.4 years; $P = 0.0054$). They were more likely to be of Hispanic ethnicity (35.7% vs. 5.2%; $P < 0.0001$) and less likely to consider themselves as white (25.0% vs. 48.6%; $P = 0.0194$). They were more likely to undergo emergent or urgent procedures ($P < 0.0001$). There were only 5 patients (5/790; 0.6%) undergoing elective procedures who tested positive. There was a greater proportion of patients who underwent diagnostic angiograms in the positive group (24.2% vs. 11.5%; $P = 0.0481$). There were no significant differences in proportion of other case types. Positive patients had greater mMeNTS scores assigned to them (9.0 vs. 7.5; $P < 0.0001$) and greater American Society of Anesthesiologists status (median 3 vs. 4; $P < 0.0001$) (Table 3). With regards to outcomes, they had increased LOS (27.5 vs. 9.1 days; $P < 0.0001$), were more likely to incur an in-hospital complication (57.6% vs. 13.3%; $P < 0.0001$) and end up in a setting other than home after discharge ($P < 0.0001$) (Table 3).

Table 3. Differences Between COVID-19—Positive and —Negative Patients Undergoing Neurosurgical and Neurointerventional Procedures During the Post-Peak Pandemic Period (June 9 to September 9)

	n (%)		
	COVID-19 (+)	**COVID-19 (−)**	***P* Value**
Total tests	35	1197	
Total cases	33	836	
Total patients	28	762	
Case category			
Surgical	20 (57.1)	634 (75.8)	0.0165*
Neurointerventional	15 (42.9)	202 (24.2)	
Positive preoperative	22 (62.9)		
Positive postoperative	13 (37.1)		
Total negative preoperative		847 (70.8)	
Total negative postoperative		350 (29.2)	
Mean age, years	51.1 ± 14.5	58.4 ± 14.3	0.0054*
Male sex	18 (64.3)	375 (49.2)	0.1172
Case acuity			<0.0001*
Emergent	15 (45.5)	119 (14.2)	<0.0001*
Urgent	13 (39.4)	147 (17.6)	0.0044*
Elective	5 (15.1)	570 (68.2)	<0.0001*
Case type			0.1057
Spine—cervical/cervicothoracic	3 (9.1)	117 (14.0)	0.6073
Spine—thoracic	1 (3.0)	26 (3.1)	0.9999
Spine—lumbar/thoracolumbar	4 (12.1)	212 (25.4)	0.1005
Craniotomy—tumor/abscess	2 (6.1)	71 (8.5)	0.9999
Craniotomy—Vascular lesions	2 (6.1)	25 (3.0)	0.2736
Craniotomy—ICH/stroke/trauma	4 (12.1)	46 (5.5)	0.1155
Cranioplasty	0 (0.0)	18 (2.2)	0.9999
Functional/pain	0 (0.0)	59 (7.1)	0.1601
CSF diversion	2 (6.1)	23 (2.8)	0.2447
Endonasal/transsphenoidal	0 (0.0)	23 (2.8)	0.9999
Diagnostic cerebral	8 (24.2)	96 (11.5)	0.0481*
Embolization—aneurysm/AVM	3 (9.1)	28 (3.3)	0.1088
Embolization—tumor	0 (0.0)	9 (1.1)	0.9999
Embolization—MMA	0 (0.0)	17 (2.0)	0.9999
Stroke thrombectomy	2 (6.1)	28 (3.3)	0.3169
Vasospasm treatment	2 (6.1)	12 (1.4)	0.0957
Spine intervention	0 (0.0)	6 (0.7)	0.9999
Carotid stent	0 (0.0)	6 (0.7)	0.9999
Other	0 (0.0)	14 (1.7)	0.9999
Race/ethnicity			<0.0001*
White Non-Hispanic	7 (25.0)	370 (48.6)	0.0194*
African-American	11 (39.3)	306 (40.2)	0.9999
Hispanic	10 (35.7)	40 (5.2)	<0.0001*
Asian	0 (0.0)	18 (2.4)	0.9999
Other	0 (0.0)	28 (3.7)	0.6186
Comorbidities			0.9994
HTN	16 (57.1)	417 (54.7)	0.8486
DM	7 (25.0)	173 (22.7)	0.8186
CAD	3 (10.7)	76 (10.0)	0.7536
CKD/ESRD	2 (7.1)	58 (7.6)	0.9999
Malignancy	3 (10.7)	104 (13.6)	0.9999
COPD/asthma	1 (3.6)	33 (4.3)	0.9999
DVT/PE	2 (7.1)	39 (5.1)	0.6519
CVA/TIA	2 (7.1)	57 (7.5)	0.9999
Mean mMeNTS score	9.0 ± 1.4	7.5 ± 1.4	<0.0001*
Mean LOS	27.5 ± 18.5	9.1 ± 9.6	<0.0001*
Median ASA status [IQR]	3 [2–4]	4 [3–4]	<0.0001*
Complications	19 (57.6)	111 (13.3)	<0.0001*
30-day readmission	6 (18.2)	80 (9.6)	0.1042
Disposition			<0.0001*
Home	4 (12.1)	604 (72.2)	<0.0001*
Death/hospice	6 (18.2)	34 (4.1)	0.0029*
Acute rehabilitation	14 (42.4)	144 (17.2)	0.0008*
Skilled nursing facility	7 (21.2)	41 (4.9)	0.0014*
Long-term care facility	2 (6.1)	13 (1.6)	0.1079

COVID-19, coronavirus disease 2019; ICH, intracranial hemorrhage; CSF, cerebrospinal fluid; AVM, arteriovenous malformation; MMA, middle meningeal artery; HTN, hypertension; DM, diabetes mellitus; CAD, coronary artery disease; CKD, chronic kidney disease; ESRD, end-stage renal disease; COPD, chronic obstructive pulmonary disease; DVT, deep venous thrombosis; PE, pulmonary embolism; CVA, cerebrovascular accident; TIA, transient ischemic attack; mMeNTS, modified Medically-Necessary, Time-Sensitive Procedures; LOS, length of stay; ASA, American Society of Anesthesiologists; IQR, interquartile range.

*Statistically significant.

Upon multivariate logistic regression to account for confounding variables, age younger than 65 years (odds ratio [OR] 7.027; 95% confidence interval [CI] 2.50–24.76; P = 0.0007), nonelective case acuity level (OR 7.319; 95% CI 2.102–34.95; P = 0.0044), presence of complications (OR 2.617; 95% CI 1.108–6.370; P = 0.0300), LOS greater than 7 days (OR 5.669; 95%CI 1.502–

21.98; P = 0.0104), non-home disposition (OR 13.12; 95%CI 3.494–64.38; P = 0.0005), and greater mMeNTS score (OR 1.590; 95%CI 1.191–2.154; P = 0.0020) were all independently associated with COVID-19–positive patients (Table 4).

DISCUSSION

In this regional study, we present a follow-up analysis of trends in neurosurgical practices at 2 tertiary care centers after the peak COVID-19 pandemic wave and upon resumption of elective cases. The incidence of perioperative COVID-19 in this population remains low at 2.9%, with a 3.6% positive rate, postoperatively. Measures to minimize nosocomial spread continue to be prioritized to keep these rates low despite significant increases in case volumes. The incidence of perioperative diagnosis of COVID-19 in the neurosurgical population is an important consideration, given the increased complications, increased LOS, poor disposition, and greater risk profiles observed in these patients.

Nosocomial Infection Risk

Our previous investigation in perioperative COVID-19 incidence revealed that the rate of COVID-19 infection in patients requiring neurosurgical intervention during peak pandemic was 5.4%.[4] This rate in the post-peak pandemic period is 2.9%, most likely due to the significant increase in number of cases and elective volume. The postoperative, positive COVID-19 rate among our patients who had a negative test before their procedure is 3.0%, remaining similar to the 2.8% rate seen during the peak pandemic period despite an increase in elective cases. This is also similar to the calculated risk of 3.7%–5% of all nosocomial infections reported among patients admitted to a neurosurgical intensive care unit before the COVID-19 pandemic.[11] Similar studies in other surgical specialties also reveal low nosocomial COVID-19 transmission rates during the same period of time.[12-15] In addition, we chose a window of 30 days' postoperatively to determine positive cases. If this window was shortened, the incidence rate may have decreased. However, all our patients who tested positive had tested positive while still in the hospital, which affirms that their COVID-19 diagnosis was hospital-acquired. This study provides further evidence that it is possible to safely support a robust elective case volume without increasing nosocomial COVID-19 infection rates among patients or providers given proper screening and safety measures.

Table 4. Multivariate Logistic Regression for COVID-19–Positive Versus COVID-19–Negative Patients During the Post-Peak Pandemic Period

Variable	OR	95% CI	*P* Value
Age <65 years	7.027	2.503–24.76	0.0007*
Male sex	2.174	0.935–5.366	0.0786
Race/ethnicity	0.6330	0.243–1.527	0.3252
Nonelective case	7.319	2.102–34.95	0.0044*
LOS >7 days	5.669	1.502–21.98	0.0104*
ASA status	0.7395	0.157–5.317	0.7243
In-hospital complication	2.617	1.108–6.370	0.0300*
Non-home disposition	13.12	3.494–64.38	0.0005*
30-day readmission	1.983	0.637–5.697	0.2159
mMeNTS score	1.590	1.191–2.154	0.0020*

COVID-19, coronavirus disease 2019; OR, odds ratio; CI, confidence interval; LOS, length of stay; ASA, American Society of Anesthesiologists; mMeNTS, modified Medically-Necessary, Time-Sensitive Procedures.
*Statistically significant.

Canceled and Delayed Cases

The pandemic has caused a shift in ethical focus from the individual patient to public health, as seen in the widespread cancellation of elective surgeries during the peak pandemic period.[16] These choices were made to conserve resources and protect patients from COVID-19. However, with the resumption of elective surgeries in the post-peak pandemic period, both the surgeon and patient must weigh the risks of COVID-19 exposure against the potential harm to a patient's health if a surgery is delayed or cancelled.[17] Twenty-six cases at the study centers were cancelled or delayed by more than 1 month either due to preoperative positive COVID-19 tests or due to the patient's fear of COVID-19 transmission. In a study in which the authors evaluated patient perceptions of COVID-19 and safety during elective orthopedic surgery in Belgium, 88% of patients whose surgeries were cancelled chose not to reschedule. As such, there may be a need to directly address patients' concerns about COVID-19 as we continue elective surgeries in the post-peak pandemic period.[18]

COVID-19–Positive Patients

Our analysis shows that patients younger than 65 years of age are significantly more likely to be positive for COVID-19 in the perioperative period (Tables 3 and 4). This trend is in line with national data displaying a greater percentage of positive tests among patients younger than 65 years of age.[19] As indicated in our previous study, patients who tested positive for COVID-19 are significantly more likely to incur a complication and require discharge to a non-home setting after surgery.[4] Interestingly, the LOS in COVID-19–positive patients remains significantly longer even after adjusting for postoperative complications and final disposition. This indicates that additional factors impact the increased LOS that we witness in this population, most likely among which is case acuity. With a significantly greater proportion of patients with COVID-19 undergoing urgent or emergent procedures, their increased LOS likely reflects the fact that COVID-19–positive patients were primarily taken to surgery only if their clinical status indicated that a delay was not feasible. The patients' preclinical status was therefore a likely contributor to the increased LOS that was subsequently observed.

The noted improvement in overall outcomes in the post-peak period with regards to complications and disposition is likely due to the increase in number of elective cases during this period compared with the majority urgent and emergent cases during the first peak. The patients in the peak period were more likely to be ill with greater risk factors and worse comorbidity profiles.

However, overall outcomes between COVID-19–positive patients during the peak period and those during the post-first peak period were similar.

Measures in Reducing Transmission Risk

Protocols at the included study centers mandate that all patients have a documented negative COVID-19 polymerase chain reaction test within 5 days of their operation. If a patient's test is positive, then it is recommended that the surgery be delayed for 1 month, at which point the patient will undergo retesting. If the surgery is urgent or emergent and the patient has a positive result or has not undergone testing, the case will proceed under full COVID-19 precautions. Moreover, mandatory approved face protection policy has been instituted for all health care workers who come in contact with patients regardless of their COVID-19 status. These measures along with organized screening protocols and widely available testing for health care workers are crucial to limiting transmission of COVID-19 in the hospital environment. Additional measures such as use of high-resolution computed tomography of the chest can provide valuable information regarding more accurate diagnostics and prognostication of patients.[20,21] However, this is not used by the study centers and may not be available for widespread use, given resource limitations.

Health care workers account for 1.1%–11.6% of total reported cases of COVID-19.[22-25] Furthermore, in a current report of 28,972 hospitalized adult cases identified by the COVID-19-Associated Hospitalization Surveillance Network (COVID-NET), 6% of adults hospitalized were health care providers with 28% of these patients needing intensive care.[26] With the winter season

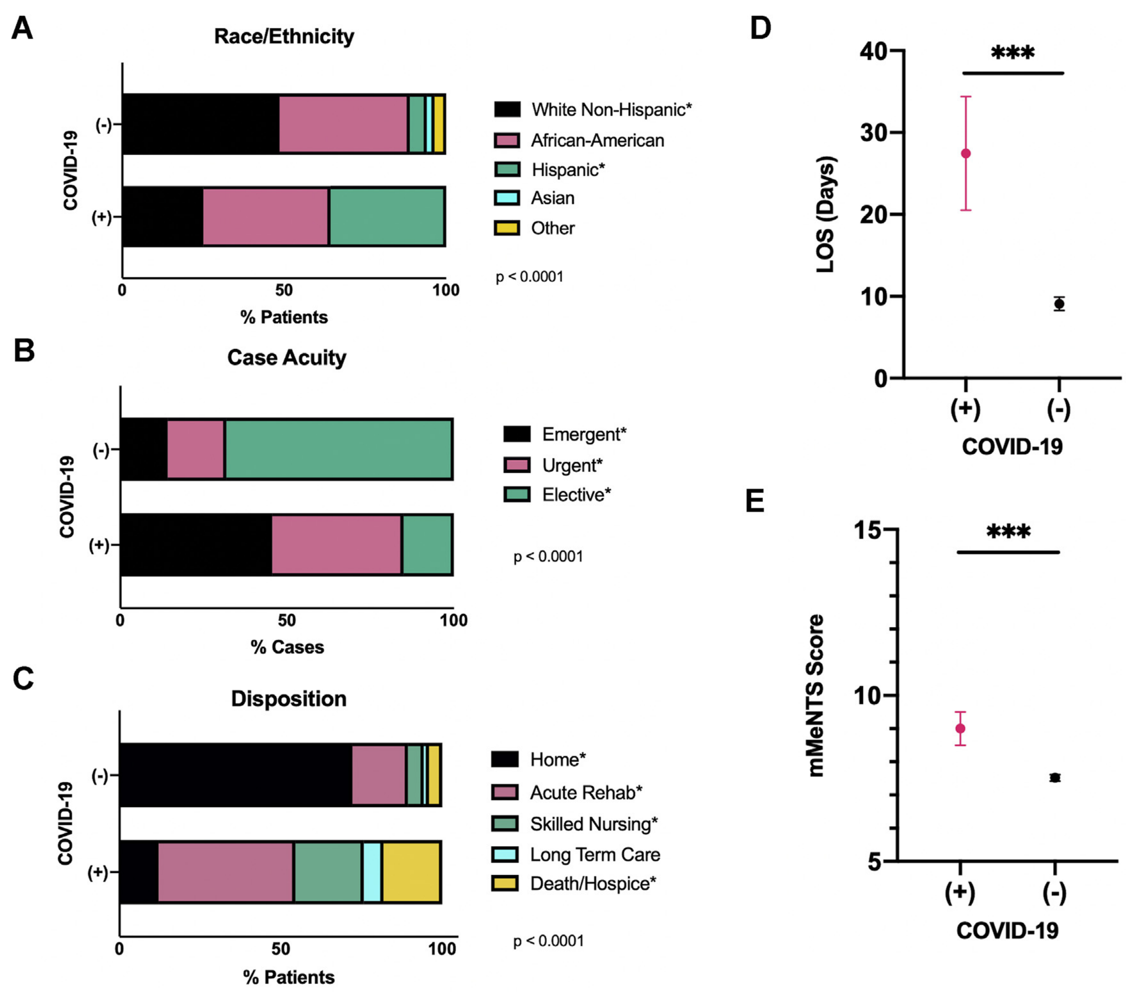

Figure 4. (**A**) Proportion of race/ethnicity patients identify with in coronavirus disease 2019 (COVID-19) –positive versus–negative patients ($P < 0.0001$). (**B**) Proportion of elective, urgent, and emergent cases in COVID-19–positive versus–negative patients ($P < 0.0001$). (**C**) Proportion of disposition assignments of COVID-19–positive versus–negative patients ($P < 0.0001$). (**D**) Length of stay (LOS) of COVID-19––positive versus negative patients (mean shown with 95% CI) (27.5 vs. 9.1 days, $P < 0.0001$). (**E**) Modified Medically-Necessary, Time-Sensitive Procedures (mMeNTS) score for COVID-19–positive versus–negative patients (mean shown with 95% confidence interval) (9.0 vs. 7.5, $P < 0.0001$). $^{***}P < 0.0001$.

approaching and possible second wave of COVID-19 interspersed with the seasonal influenza virus, protective measures to minimize infection risk are crucial to preserving valued resources within the health care system.[27] This could be accomplished by strict vaccination guidelines for staff and continued strict protocols for COVID-19 testing within close to procedure day, preferably within 48 hours.[28] Several studies also have recommended avoiding awake neurosurgical operations, minimizing procedure duration, and unnecessary operating room exit and entry.[29,30] A recent study on incidence of transmission among health care workers in a surgical environment showed that only 1 of 394 (0.2%) potentially exposed workers tested positive.[31]

Risk Stratification

To safely schedule elective surgical cases during the post-peak pandemic period, the study centers used the mMeNTS risk-stratification tool previously described.[4] Originally published as a MeNTS score, it was designed to triage medically necessary and time-sensitive cases while preserving resources and protecting patients as well as health care personnel from adverse outcomes associated with nosocomial COVID-19 infection.[32] The original scoring system is based on a 105-point scale with graded factors falling into 3 categories: procedure, disease, and patient. This was modified to a 15-point scale to simplify its use. If a patient's mMeNTS score is greater than 10, it is advised that the surgery be postponed.

There is limited literature on the effectiveness of the mMeNTS scoring tool in stratifying elective surgeries. Cohn et al.[33] criticized this tool for its inability to appropriately stratify time-sensitive cases across all specialties. Many other surgical subspecialties also have expressed similar concerns about the subjective nature of this tool and the skewed preferences for favoring procedures toward the young and healthy.[34,35] In neurosurgery, this may be especially true in oncologic care, as well as cases of stable spinal pathology causing intolerable pain. As such, there have been a number of studies suggesting neurosurgery-specific stratification tools, which may be useful alone or in combination with the mMeNTS system. Such scoring systems can include neurosurgery-specific elements for both cranial and spine cases such as the presence of neurologic deficit, radiographic parameters, and need for intensive care unit stay[9,36,37] Despite limitations, our previous study as well as this current one shows that there is a clear difference in mMeNTS score between COVID-19–positive and–negative patients (Figure 4E), suggesting that patients with greater scores are more prone to contracting the virus and more likely to have poor outcomes. The fact that only 2.3% (18/790) of patients undergoing intervention in our study had a mMeNTS score greater than 10 suggests that those with greater scores are not undergoing procedures, given a greater risk profile. Ultimately, acceptable guidelines specific to neurosurgical practice may be needed to increase the objectivity of this tool as we prepare for a potential subsequent wave of the COVID-19 pandemic.

Limitations

This is a 2-center, retrospective study of COVID-19 that may not be generalizable to other regions, given the varying degrees of impact the pandemic has on different regions as well as the variability in methodology of triage and patient care. Furthermore, it only included patients undergoing procedures under general anesthesia, thus excluding inpatients not undergoing procedures as well outpatient encounters. All patients in the post-peak pandemic period were tested for COVID-19 preoperatively, compared with about two-thirds of those in the peak pandemic period; this complicates the ability to risk stratify patients based on COVID-19 incidence and outcome measures from one time period alone. The assignment of mMeNTS score and case acuity was completed by the surgeon and/or providers, which could be biased and based on the circumstances provided for each patient case. Larger, multicenter and multiregional studies are warranted to improve further strategic planning for optimal patient care and to provide a more representative view of the perioperative COVID-19 risk in the neurosurgical population.

CONCLUSIONS

The incidence of COVID-19 infection in patients undergoing neurosurgical intervention during the post-peak pandemic period in Washington, DC, remains low but should be taken into consideration when scheduling cases. COVID-19–positive patients face increased LOS, complications, and disposition to rehabilitation or mortality. The mMeNTS score can be used when scheduling elective cases to risk stratify patients. Perioperative testing remains a priority for all patients undergoing neurosurgical procedures. To maximize the safety of providers and patients, precautions need to continue to be put into place as the possibility of further surges in the pandemic become reality.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Kwadwo Sarpong: Methodology, Resources, Visualization, Data curation, Investigation, Writing - original draft. **Ehsan Dowlati:** Conceptualization, Investigation, Data curation, Formal analysis, Writing - original draft. **Charles Withington:** Data curation, Writing - original draft. **Kelsi Chesney:** Data curation, Writing - original draft. **William Mualem:** Data curation, Writing - original draft. **Kathryn Hay:** Data curation, Writing - original draft. **Tianzan Zhou:** Validation, Formal analysis, Writing - original draft. **Jordan Black:** Data curation. **Matthew Shashaty:** Data curation. **Christopher G. Kalhorn:** Supervision, Writing - review & editing. **Mani N. Nair:** Supervision, Writing - review & editing. **Daniel R. Felbaum:** Supervision, Writing - review & editing.

REFERENCES

1. World Health Organization. Weekly epidemiological update - 17 November 2020. Published November 17, 2020. Available at: https://www.who.int/publications/m/item/weekly-epidemiological-update—17-november-2020. Accessed November 22, 2020.

2. American College of Surgeons. COVID-19: Recommendations for Management of Elective Surgical Procedures. Available at: https://www.facs.org/covid-19/clinical-guidance/elective-surgery. Accessed July 5, 2020.

3. Office of the Mayor. Coronavirus Data. Government of the District of Columbia. Available at:

https://coronavirus.dc.gov/page/coronavirus-data. Accessed July 6, 2020.

4. Dowlati E, Zhou T, Sarpong K, et al. Case volumes and perioperative coronavirus disease 2019 incidence in neurosurgical patients during a pandemic: experiences at two tertiary care centers in Washington, DC. *World Neurosurg*. 2020;143:e550-e560.

5. Centers for Disease Control and Prevention. Coronavirus Disease 2019 (COVID-19). Published February 11, 2020. Available at: https://www.cdc.gov/coronavirus/2019-ncov/need-extra-precautions/racial-ethnic-minorities.html. Accessed July 5, 2020.

6. Macdonald N, Clements C, Sobti A, Rossiter D, Unnithan A, Bosanquet N. Tackling the elective case backlog generated by Covid-19: the scale of the problem and solutions. *J Public Health (Oxf)*. 2020;42:712-716.

7. Jain A, Jain P, Aggarwal S. SARS-CoV-2 impact on elective orthopaedic surgery: implications for post-pandemic recovery. *J Bone Joint Surg Am*. 2020;102:e68.

8. Petr O, Glodny B, Brawanski K, et al. Immediate versus delayed surgical treatment of lumbar disc herniation for acute motor deficits: the impact of surgical timing on functional outcome. *Spine (Phila Pa 1976)*. 2019;44:454-463.

9. Jean WC, Ironside NT, Sack KD, Felbaum DR, Syed HR. The impact of COVID-19 on neurosurgeons and the strategy for triaging non-emergent operations: a global neurosurgery study. *Acta Neurochir (Wien)*. 2020;162:1229-1240.

10. El Aferni A, Guettari M, Tajouri T. Mathematical model of Boltzmann's sigmoidal equation applicable to the spreading of the coronavirus (Covid-19) waves [e-pub ahead of print]. *Environ Sci Pollut Res Int*. https://doi.org/10.1007/s11356-020-11188-y, accessed November 1, 2020.

11. Abulhasan YB, Rachel SP, Châtillon-Angle M-O, et al. Healthcare-associated infections in the neurological intensive care unit: results of a 6-year surveillance study at a major tertiary care center. *Am J Infect Control*. 2018;46:656-662.

12. Tabourin T, Sarfati J, Pinar U, et al. Postoperative assessment of nosocomial transmission of COVID-19 after robotic surgical procedures during the pandemic [e-pub ahead of print]. *Urol Oncol* https://doi.org/10.1016/j.urolonc.2020.09.008, accessed November 1, 2020.

13. Kapoor D, Perwaiz A, Singh A, Chaudhary A. Elective gastrointestinal surgery in COVID times [e-pub ahead of print]. *Indian J Surg*. https://doi.org/10.1007/s12262—020—02642—9, accessed November 1, 2020.

14. Ji C, Singh K, Luther AZ, Agrawal A. Is elective cancer surgery safe during the COVID-19 pandemic? *World J Surg*. 2020;44:3207-3211.

15. Stevenson JD, Evans S, Morris G, et al. Mortality of high-risk orthopaedic oncology patients during the COVID-19 pandemic: a prospective cohort study [e-pub ahead of print]. *J Surg Oncol*. https://doi.org/10.1002/jso.26127, accessed October 28, 2020.

16. Angelos P. Surgeons, ethics, and COVID-19: early lessons learned. *J Am Coll Surg*. 2020;230:1119-1120.

17. Stahel PF. How to risk-stratify elective surgery during the COVID-19 pandemic? *Patient Saf Surg*. 2020;14:8.

18. Hernigou J, Valcarenghi J, Safar A, et al. Post-COVID-19 return to elective orthopaedic surgery-is rescheduling just a reboot process? Which timing for tests? Is chest CT scan still useful? Safety of the first hundred elective cases? How to explain the "new normality health organization" to patients? *Int Orthop*. 2020;44:1905-1913.

19. Centers for Disease Control and Prevention. COVID Key Updates for Week 42. Centers for Disease Control and Prevention. Published October 23, 2020. Available at: https://www.cdc.gov/coronavirus/2019-ncov/covid-data/covidview/index.html. Accessed October 29, 2020.

20. Prokop M, van Everdingen W, van Rees Vellinga T, et al. CO-RADS: a categorical CT assessment scheme for patients suspected of having COVID-19-definition and evaluation. *Radiology*. 2020;296:E97-E104.

21. Huybens EM, Bus MPA, Massaad RA, et al. What is the preferred screening tool for COVID-19 in asymptomatic patients undergoing a surgical or diagnostic procedure? *World J Surg*. 2020;44:3199-3206.

22. CDC COVID-19 Response Team. Characteristics of Health Care Personnel with COVID-19 —United States, February 12-April 9, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69:477-481.

23. Folgueira MD, Munoz-Ruiperez C, Alonso-Lopez MA, Delgado R. SARS-CoV-2 infection in health care workers in a large public hospital in Madrid, Spain, during March 2020 [e-pub ahead of print]. *medRxiv*. https://doi.org/10.1101/2020.04.07.20055723, accessed October 28, 2020.

24. Rivett L, Sridhar S, Sparkes D, et al. Screening of healthcare workers for SARS-CoV-2 highlights the role of asymptomatic carriage in COVID-19 transmission. *eLife*. 2020;9.

25. Lai X, Wang M, Qin C, et al. Coronavirus disease 2019 (COVID-2019) infection among health care workers and implications for prevention measures in a tertiary hospital in Wuhan, China. *JAMA Netw Open*. 2020;3:e209666.

26. Kambhampati AK. COVID-19—Associated Hospitalizations Among Health Care Personnel—COVID-NET, 13 States, March 1—May 31, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69:1576-1583.

27. Ehrlich H, Boneva D, Elkbuli A. The intersection of viral illnesses: a seasonal influenza epidemic amidst the COVID-19 pandemic. *Ann Med Surg*. 2020;60:41-43.

28. De Biase G, Freeman W, Elder B, et al. Path to reopening surgery in the COVID-19 pandemic: neurosurgery experience. *Mayo Clin Proc Innov Qual Outcomes*. 2020;4:557-564.

29. Daci R, Natarajan SK, Johnson MD. Letter: Safety considerations for neurosurgical procedures during the COVID-19 pandemic. *Neurosurgery*. 2020;87:E239-E240.

30. Flexman AM, Abcejo AS, Avitsian R, et al. Neuroanesthesia practice during the COVID-19 pandemic: recommendations from Society for Neuroscience in Anesthesiology and Critical Care (SNACC). *J Neurosurg Anesthesiol*. 2020;32:202-209.

31. Parkulo MA, Brinker TM, Bosch W, Palaj A, DeRuyter ML. Risk of SARS-CoV-2 transmission among coworkers in a surgical environment [e-pub ahead of print]. *Mayo Clin Proc*. https://doi.org/10.1016/j.mayocp.2020.10.016, accessed October 28, 2020.

32. Prachand VN, Milner R, Angelos P, et al. Medically necessary, time-sensitive procedures: scoring system to ethically and efficiently manage resource scarcity and provider risk during the COVID-19 pandemic. *J Am Coll Surg*. 2020;231:281-288.

33. Cohn JA, Ghiraldi EM, Uzzo RG, Simhan J. A critical appraisal of the American College of Surgeons Medically Necessary, Time Sensitive Procedures (MeNTS) Scoring System, urology consensus recommendations and individual surgeon case prioritization for resumption of elective urological surgery during the COVID-19 pandemic [e-pub ahead of print]. *J Urol*. https://doi.org/10.1097/JU.0000000000001315, accessed November 1, 2020.

34. Waxman S, Garg A, Torre S, et al. Prioritizing elective cardiovascular procedures during the COVID-19 pandemic: the cardiovascular medically necessary, time-sensitive procedure scorecard. *Catheter Cardiovasc Interv*. 2020;96:E602-E607.

35. Marfori CQ, Klebanoff JS, Wu CZ, Barnes WA, Carter-Brooks CM, Amdur RL. Reliability and validity of 2 surgical prioritization systems for reinstating nonemergent benign gynecologic surgery during the COVID-19 pandemic [e-pub ahead of print]. *J Minim Invasive Gynecol*. https://doi.org/10.1016/j.jmig.2020.07.024, accessed November 1, 2020.

36. Sciubba DM, Ehresman J, Pennington Z, et al. Scoring system to triage patients for spine surgery in the setting of limited resources: application to the coronavirus disease 2019 (COVID-19) pandemic and beyond. *World Neurosurg*. 2020;140:e373-e380.

37. Lwu S, Paolucci EO, Hurlbert RJ, Thomas KC. A scoring system for elective triage of referrals: Spine Severity Score. *Spine J*. 2010;10:697-703.

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