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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.2 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...
alone, 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. In addition, within neurosurgery, many surgical procedures are time-sensitive yet not necessarily non-elective—patients treated sooner may benefit most from surgical intervention. 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. 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
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. Outcomes data collected included postoperative complications, length of stay (LOS), discharge disposition, 30-day readmission, preoperative COVID-19 status, postoperative COVID-19 status at ≤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. χ² 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). 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.
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 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)**

|                       | 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      | 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      | 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* |
| Cranioctomy—tumor/abscess | 53 (13.0) | 73 (11.2) | 0.3800 |
| Cranioctomy—vascular lesions | 25 (6.2) | 27 (4.1) | 0.1454 |
| Cranioctomy—ICH/CVA/truma | 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/transphenoidal | 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       |

Continues

**Table 1. Continued**

|                       | March 8 to June 8 | June 9 to September 9 | \( P \) Value |
|-----------------------|-------------------|-----------------------|--------------|
| 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)              | 0.7788       |
| CVA/TIA               | 25 (6.5)          | 49 (8.0)              | 0.3877       |
| Mean mMMeNTS 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; mMMeNTS, modified Medically-Necessary, Time-Sensitive Procedures; ASA, American Society of Anesthesiologists; IQR, interquartile range; LOS, length of stay.

*Statistically significant.
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)

|                         | March 8 to June 8 | June 9 to September 9 | P Value |
|-------------------------|-------------------|------------------------|---------|
| n (%)                   |                   |                        |         |
| 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        | 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        | 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)               | 0.5403  |
| 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                 |         |

Continues

Table 2. Continued

|                          | March 8 to June 8 | June 9 to September 9 | P Value |
|--------------------------|-------------------|------------------------|---------|
| 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               | 16 (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...
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).
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 5.669; 95% CI 1.502–

### 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)

|                          | 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* |
| Neurointervention        | 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**          |              |              |         |
| 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  |
| Craniootomy—tumor/abscess | 2 (6.1)    | 71 (8.5)     | 0.9999  |
| Craniootomy—Vascular lesions | 2 (6.1)    | 25 (3.0)     | 0.2736  |
| Craniootomy—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)      | 58 (7.1)     | 0.1601  |
| CSF diversion            | 2 (6.1)      | 23 (2.8)     | 0.2447  |
| Endonasal/transphenoidal  | 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)     | 0.9957  |
| Spine intervention       | 0 (0.0)      | 6 (0.7)      | 0.9999  |
| Carotid stent            | 0 (0.0)      | 6 (0.7)      | 0.9999  |

Continues

|                          | COVID-19 (+) | COVID-19 (−) | P Value |
|--------------------------|--------------|--------------|---------|
| 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.
21.98; \( P = 0.0104 \) ), non-home disposition (OR 13.12; 95%CI 3.694–64.38; \( P = 0.0005 \) ), and greater mMeNTS score (OR 1.990; 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 spread continued to be 3.5%–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. Similar studies in other surgical specialties also reveal low nosocomial COVID-19 transmission rates during the same period of time. 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.

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. 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. 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.

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. 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. 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.

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        |
| Non-elective 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.
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. 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. 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. With the winter season...
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. 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. Several studies also have recommended avoiding awake neurosurgical operations, minimizing procedure duration, and unnecessary operating room exit and entry. 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.

**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. 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. 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. Cohen et al. 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. 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. 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 Mualen: 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.

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27. Conflict of interest statement: The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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