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Impact of COVID-19 on Neurosurgery in Brazil's Health System: The Reality of a Developing Country Affected by the Pandemic

Leonardo J.M. de Macêdo Filho^{1,2}, Ana Carolina A. Aragão², Vito Thayson D. dos Santos², Livia B.A. Galvão², Nathan A. Shlobin³, Gaetano De Biase¹, Paola Suarez-Meade¹, Joao Paulo C. Almeida⁴, Alfredo Quinones-Hinojosa¹, Lucas A.F. de Albuquerque⁵

■ **BACKGROUND:** The coronavirus disease identified in 2019 (COVID-19) pandemic changed neurosurgery protocols to provide ongoing care for patients while ensuring the safety of health care workers. In Brazil, the rapid spread of the disease led to new challenges in the health system. Neurooncology practice was one of the most affected by the pandemic due to restricted elective procedures and new triage protocols. We aim to characterize the impact of the pandemic on neurosurgery in Brazil.

■ **METHODS:** We analyzed 112 different types of neurosurgical procedures, with special detail in 11 neurooncology procedures, listed in the Brazilian Hospital Information System records in the DATASUS database between February and July 2019 and the same period in 2020. Linear regression and paired t-test analyses were performed and considered statistically significant at $P < 0.05$.

■ **RESULTS:** There was an overall decrease of 21.5% (28,858 cases) in all neurosurgical procedures, impacting patients needing elective procedures (−42.46%) more than emergency surgery (−5.93%). Neurooncology procedures decreased by 14.89%. Nonetheless, the mortality rate during hospitalization increased by 21.26%. Linear regression analysis in hospitalizations (Slope = 0.9912 ± 0.07431 ; CI [95%] = $0.8231-1.159$) and total cost (Slope = 1.03 ± 0.03501 ; CI [95%] = $0.9511-1.109$) in the 11 different types of neurooncology procedures showed a $P < 0.0001$. The

mean cost per type of procedure showed an 11.59% increase ($P = 0.0172$) between 2019 and 2020.

■ **CONCLUSIONS:** The COVID-19 pandemic has increased mortality, decreased hospitalizations, and therefore decreased overall costs, despite increased costs per procedure for a variety of neurosurgical procedures. Our study serves as a stark example of the effect of the pandemic on neurosurgical care in settings of limited resources and access to care.

INTRODUCTION

Since the first human cases of the disease caused by the new coronavirus SARS-CoV-2 (COVID-19) were reported in Wuhan, China in December 2019, the health systems of all nations around the world have been forced to respond to the pandemic by increasing safety measures and altering protocols in order to provide continued patient care. In Brazil, the number of hospital beds is approximately 426,380 with 62,000 intensive care unit (ICU) beds. The occupancy rate of ICU was ~90%, and the mortality rate was 5.68% until the second week of April, the beginning of the first wave. The COVID-19 pandemic represents another increase in the compendium of complex situations that occurred in social, economic, and political aspects in the past decade for the world and, more importantly, to low-income countries like Brazil.^{1,2} While the federal government attempted to alleviate the economic impacts of the pandemic to prevent

Key words

- COVID-19
- Developing countries
- Neurosurgery
- Socioeconomic factors

Abbreviations and Acronyms

DATASUS: Departamento de Informática do SUS

GDP: Gross domestic product

HDI: Human Development Index

SIHSUS: Sistema de Informações Hospitalares do Sistema, Único de Saúde/Brazilian Hospital Information System

SUS: Sistema Único de Saúde/Brazilian Unified Health System

From the ¹Department of Neurological Surgery, Mayo Clinic, Jacksonville, Florida, USA;

²Health Science Center, University of Fortaleza, Fortaleza, Ceará, Brazil; ³Feinberg School of Medicine, Northwestern University, Chicago, Illinois, USA; ⁴Division of Neurosurgery, Toronto Western Hospital, University of Toronto, Toronto, Ontario, Canada; and ⁵Department of Neurosurgery, General Hospital of Fortaleza, Fortaleza, Ceará, Brazil

To whom correspondence should be addressed: Leonardo J.M. de Macêdo Filho, M.D.
[E-mail: demacedofilho.leonardo@mayo.edu]

Citation: World Neurosurg. (2021) 155:e142-e149.

<https://doi.org/10.1016/j.wneu.2021.08.030>

Journal homepage: www.journals.elsevier.com/world-neurosurgery

Available online: www.sciencedirect.com

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impending financial turmoil, preventive measures such as social distancing were not widely adopted. The difficulty of facing the pandemic due to current political crisis, acute socioeconomic disparities, large territory, and large population led to rapid spread of the disease in Brazilian territories and new challenges within the public and private health systems.³

In neurosurgical practice, protocols that were instituted in response to the pandemic, including more beds for the infected, greater demand for drugs and materials in the management of COVID-19 patients, and reallocation of health professionals, have increased strain on the health system and the workload of neurosurgeons.⁴ During the pandemic, patients suffering from neurosurgical diseases were instructed to stay at home while the surgical assessment was carried out. The practice of neurosurgery in Brazil during COVID-19 has focused on prioritizing procedures considering severity of the condition, risk of intraoperative viral transmission in elderly patients and patients with comorbidities, and effects on postoperative length of stay due to increased demand for available beds during the pandemic.⁵

We aim to characterize the impact of the pandemic on neurologic elective and emergency surgeries on neurosurgical procedures in Brazilian regions due to greatly restricted electives procedures and new protocols on the triage of neurosurgery patients, with special emphasis on neurooncology because it was one of the most affected subspecialties by the pandemic.^{2,4,5} We used a reliable health information database from Brazil,⁶⁻⁸ The new coronavirus pandemic has changed protocols and access to neurosurgery worldwide.^{4,5,9,10} We hypothesized that in Brazil the

COVID-19 pandemic had an even greater impact due to the high incidence of the disease in the country associated with the difficulty of facing the pandemic,¹⁻³ bringing consequences in mortality rate, number of hospitalizations, and cost of procedures.

METHODS

Data Collection

We analyzed 112 different types of neurosurgical procedures listed in the Brazilian Hospital Information System (Sistema de Informações Hospitalares do Sistema Único de Saúde, SIHSUS) records in the Departamento de Informática do SUS (DATASUS) database. DATASUS is the information technology department of the Brazilian Unified Health System (Sistema Único de Saúde; SUS) and was developed and is maintained by the Brazilian federal government.⁶ It collects, processes, disseminates, and manages health information from the public sector under the SUS, as well as from the private sector. DATASUS is an administrative database with information from all hospitalizations reimbursed by the SUS. It corroborates with a successful Brazilian experience in the field of health information.^{7,8}

Moreover, we detailed 11 different types of neurooncology procedures (microsurgeries for peripheral nerves, orbital, and spinal and intracranial tumors) between February and July of 2019 and during same period in 2020. There were not differences between the 2 sample populations (e.g., age, sex) in the respective periods. For all included procedures we analyzed the following: total cost, mean cost, and total hospitalizations (Table 1 and Figure 1).

Table 1. Total Cost: Mean Cost and Total Hospitalizations in Elective Neurooncology Procedures Between February and July of 2019 and 2020

Neurosurgical Procedures	Total Cost		Mean Cost		Total Hospitalizations	
	2019	2020	2019	2020	2019	2020
Microsurgical treatment for peripheral nerve tumor/neuroma	\$13,229.36	\$5953.00	\$100.22	\$93.02	132	64
Craniotomy to remove brain tumors from the posterior fossa	\$80,526.26	\$70,986.07	\$1032.39	\$1245.37	78	57
Craniotomy for intracranial tumor removal	\$46,919.99	\$43,732.19	\$680.00	\$780.93	69	56
Intradural and extramedullary tumor microsurgery	\$25,369.48	\$21,430.59	\$634.24	\$714.35	40	30
Microsurgery of the medullary tumor with complementary technique	\$32,154.94	\$34,755.01	\$730.79	\$789.89	44	44
Microsurgery of spinal tumors	\$31,651.91	\$29,291.07	\$736.09	\$732.28	43	40
Microsurgery skull base tumors	\$53,071.60	\$33,124.54	\$1001.35	\$1068.53	53	31
Microsurgery for orbital tumors	\$11,853.37	\$9919.80	\$564.45	\$551.10	21	18
Microsurgery for intracranial tumors	\$258,738.01	\$234,923.79	\$1043.30	\$1077.63	248	218
Microsurgery for intracranial tumors with complementary technique	\$350,673.12	\$374,682.09	\$1120.36	\$1142.32	313	328
Extradural spinal tumor resection	\$10,361.30	\$9765.98	\$518.07	\$574.47	20	17

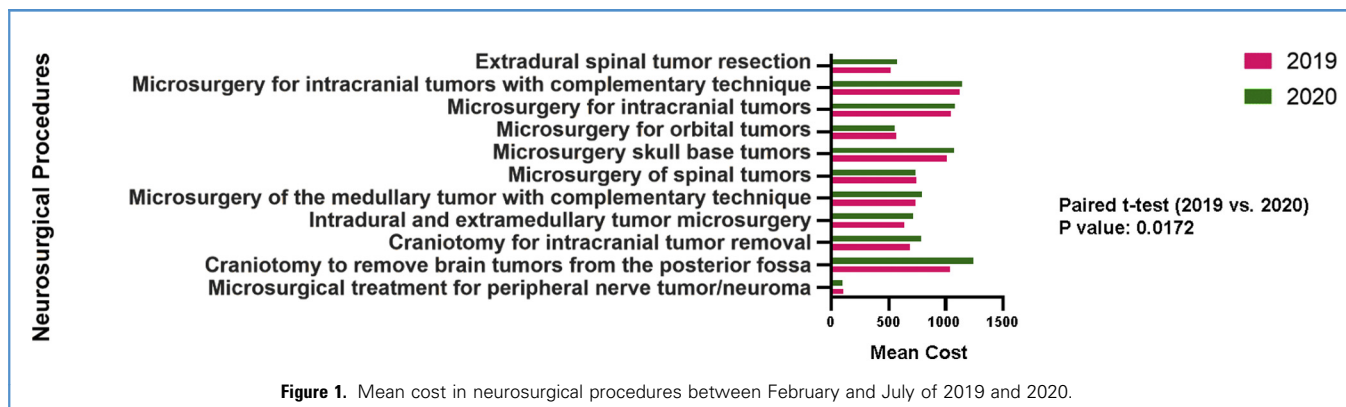


Figure 1. Mean cost in neurosurgical procedures between February and July of 2019 and 2020.

The Brazilian federal government divides its 27 federation units (26 states and 1 federal district) into 5 geographic regions (i.e., North, Northeast, Midwest, Southeast, and South) to assist in the implementation and maintenance of public policies. These geographic regions differ in gross domestic product (GDP) and Human Development Index (HDI).¹¹ For each Brazilian region, we analyzed the following for all different types of neurosurgical procedures: total number of elective and emergency hospitalizations, total cost of elective and emergency procedures, total cost of all neurosurgery procedures, and mortality rate (Table 2).

For international comparison, we converted the Brazilian real (R\$) to the U.S. dollar (US\$). The corresponding dollar exchange rate on the day of data collection (August 5, 2020) was R\$1, equivalent to US\$0.19. The cost of a particular procedure is fixed in the hospital; however, the cost of hospitalization is different based on length of stay, complexity, and patients' outcomes and complications. The mortality rate is the hospital mortality rate per 100 people hospitalized for the specific neurosurgical procedure. The mean length of stay is the sum of the days from admission to the day of discharge divided by the number of patients hospitalized for each neurosurgical procedure.

Statistical Analysis

We performed a linear regression analysis using the software Prism 7.0 (GraphPad Software Inc.). The results were expressed with scatter plots and slope lines \pm standard error and 95% confidence intervals. We analyzed the total number of hospitalizations (Figure 2) and total costs (Figure 3) in neuro-oncology surgical procedures for resection of 11 different type of tumors, between February and July 2019, comparing it with the same period of 2020. We conducted a Shapiro-Wilk test to check the normality of the data, followed by a matched-pair t-test of the mean cost in the 11 different types of neurooncology procedures (see Figure 1). We considered the analyses to be statistically significant at $P < 0.05$.

RESULTS

Neurosurgery Hospitalizations and Mortality Rate in COVID-19 Pandemic

Between February and June of 2019, 36,766 neurosurgical cases were performed (mean of 7353.2 cases/month) in Brazil, of which 21,089

(57.4%) were considered to be emergent cases and 15,677 (42.6%) were elective. During the same period in 2020, since the beginning of the COVID-19 pandemic, there was a 21.5% decrease (28,858 cases) in the number of procedures, with a greater impact in patients needing elective procedures (-42.46%) when compared with patients needing emergency surgery (-5.93%) (see Table 2).

With regards to Brazilian regions, the Northeast region showed a decrease of 24.78% in neurosurgery procedures cases for brain/spine tumors, followed by the South (-22.32%), Southeast (-21.87%), North (-19.69%), and Midwest (-7.92%) regions. The Southeast region, the region most heavily affected by SARS-CoV-2, experienced a 45.3% decrease in elective cases and a 2.26% decrease in emergency cases compared with the same period of 2019 (see Table 2). The Northeast region had a higher reduction in elective (-46.02%) and emergency cases (-13.78%). The North region was the region with the greatest decrease in emergency cases (-18.9%) and had a 19.69% reduction in electives cases (see Table 2). The Northeast and North regions have the lowest GDP and HDI in Brazil and fewer resources devoted to medical care.

There were 1061 neurosurgical cases for brain/spine tumors (mean of 212.2 cases/month) between February and June 2019 in Brazil. During the same period in 2020, there were 903 tumor-related surgeries (mean of 180.6 cases/month). An important reduction of 14.89% of neurooncologic cases was noted during the time of the pandemic. Microsurgery for intracranial tumor with complementary technique (i.e., use of surgical adjuncts) was the most frequently performed procedure in both periods, followed by microsurgery for intracranial tumor and microsurgical treatment for peripheral nerve tumor/neuroma (Table 1).

In regards to hospitalization days, microsurgical treatment of peripheral nerve tumor/neuroma showed a decrease of 51.52% during the pandemic, followed by the skull base tumor (-41.51%) in both elective and emergency cases (see Table 1). Moreover, we performed a linear regression analysis of the relationship between the hospitalizations for neurooncology procedures in 2019 and 2020 (Slope = 0.9912 ± 0.07431 ; CI [95%] = $0.8231-1.159$), and we found a significant P value ($P < 0.0001$). Comparison of the residual values of these procedures and the microsurgical treatment for peripheral nerve tumor/neuroma suggested a higher than estimated decrease in the pandemic period (Figure 2).

Table 2. Electives Total Costs and Hospitalizations, Emergency Total Costs and Hospitalizations, Mortality Rate, and Total Cost of All Neurosurgery Procedures in Brazilian Regions Between February and July of 2019 and 2020

Region of Brazil	Elective Procedures, Total Cost		Emergency Procedures, Total Cost		Electives Hospitalizations		Emergency Hospitalizations		Total Cost of Neurosurgical Procedures		Mortality Rate	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
North	\$73,500.97	\$78,882.74	\$942,603.49	\$789,717.33	517	405	1296	1051	\$1,273,000.00	\$1,059,344.62	9.5	9.29
Northeast	\$180,877.30	\$141,366.17	\$3,848,437.65	\$3,498,531.75	2508	1354	4842	4175	\$5,049,635.13	\$4,342,071.52	8.27	9.97
Southeast	\$434,440.70	\$399,560.50	\$7,815,661.21	\$8,214,503.13	7589	4151	9088	8863	\$10,897,364.5	\$10,432,346.53	9.06	10.99
South	\$156,080.00	\$196,246.82	\$3,680,185.24	\$3,471,235.78	4077	2477	4393	4102	\$4,999,469.52	\$4,412,331.62	4.54	6.53
Midwest	\$69,650.45	\$52,507.85	\$1,301,286.82	\$1,525,197.45	986	633	1490	1647	\$1,640,403.00	\$1,757,824.14	8.47	9.69

The mortality rate during the hospitalization in neurosurgical cases increased by 22.26% in the pandemic period. The South region showed the highest increase (44.83%) followed by Southeast (21.30%), Northeast (20.56%), and Midwest (14.40%) regions. The North region experienced a small reduction (−2.21%) in the mortality rate (Table 2).

Economic Impact of the COVID-19 Pandemic on Neurosurgical Procedures

Although there was a decrease in number of cases, the mean cost of all neurosurgical procedures increased by 18.23% that could be explained due to high demand of health professionals in the pandemic period. The Southeast region had the highest cost increase (22.53%) followed by Midwest (16.37%), South (15%), Northeast (14.31%) and North (3.62%) regions (see Table 2).

In elective cases, the mean cost increase of neurosurgical procedures in the pandemic period was 65.06%. Comparing the Brazilian regions, the South region reported an increase of 106.95% followed by the Southeast (68.14%), Northeast (44.77%), North (37%), and Midwest (17.43%) regions. However, the mean cost of emergency cases only increased 5.77% in the pandemic period. The Southeast had an increase of 7.53%, followed by Midwest (6.03%), Northeast (5.43%), North (3.31%), and South (1.01%) regions.

We further compared elective neuro-oncology cases between the two study periods. For these, the mean cost per procedure type increased 11.59% ($P = 0.0172$) in the pandemic period, however, as a result of fewer hospitalizations the overall cost paid by the government decreased 5.02% (see Table 1 and Figure 1).

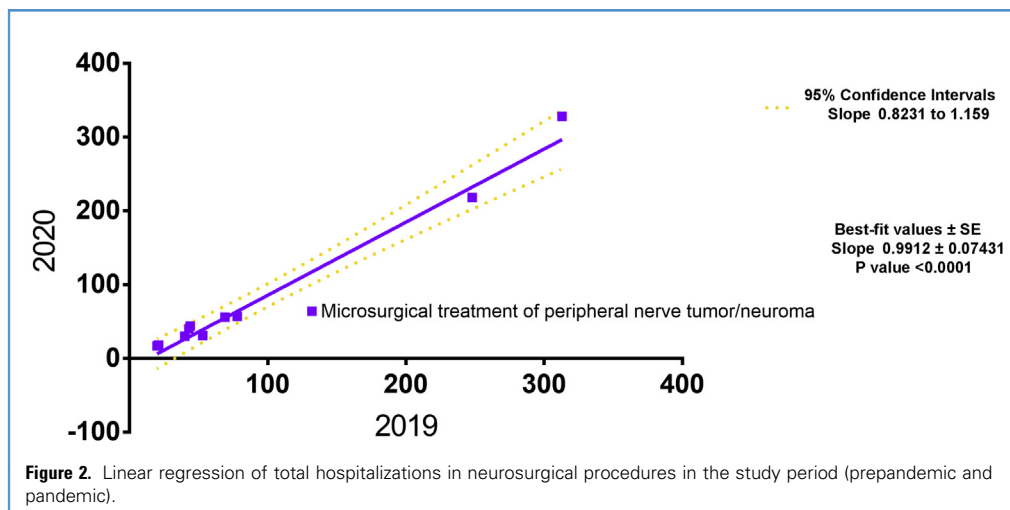
Craniotomy to remove brain tumors from the posterior fossa showed an increase of 20.63% in mean cost per case, followed by craniotomy for intracranial tumor removal (14.84%), intradural and extramedullary tumor microsurgery (12.63%), and microsurgery for intracranial tumors with the use of surgical adjuncts (10.89%). Moreover, there was a mean cost decrease in microsurgical treatment for peripheral nerve tumor/neuroma (−7.19%), microsurgery for orbital tumors (−2.36%), and microsurgery of spinal tumors (−0.52%).

We performed a linear regression analysis of the total cost between the 11 neuro-oncology procedures in 2019 and 2020 [$\text{Slope} = 1.03 \pm 0.03501$; $\text{CI}(95\%) = 0.9511 - 1.109$] and we found a significant P -value ($P < 0.0001$) for the correlation between these years. Comparison of the residual values in the linear regression of these procedures showed a higher than estimated decrease during the pandemic period in microsurgery for intracranial tumors and microsurgery for skull base tumors (Figure 3).

DISCUSSION

Mortality Rate

Neurosurgical mortality rates change according to variables corresponding to the condition/disease, such as complications, and the health system environment. In our study, we found a 22.26% increase in the mortality rate during the hospitalization in neurosurgical procedures during the COVID-19 pandemic. Regions with a higher GDP, such as the South and Southeast in Brazil, were also affected despite having a higher number of hospitals and often better resources.^{12,13} Resources have been

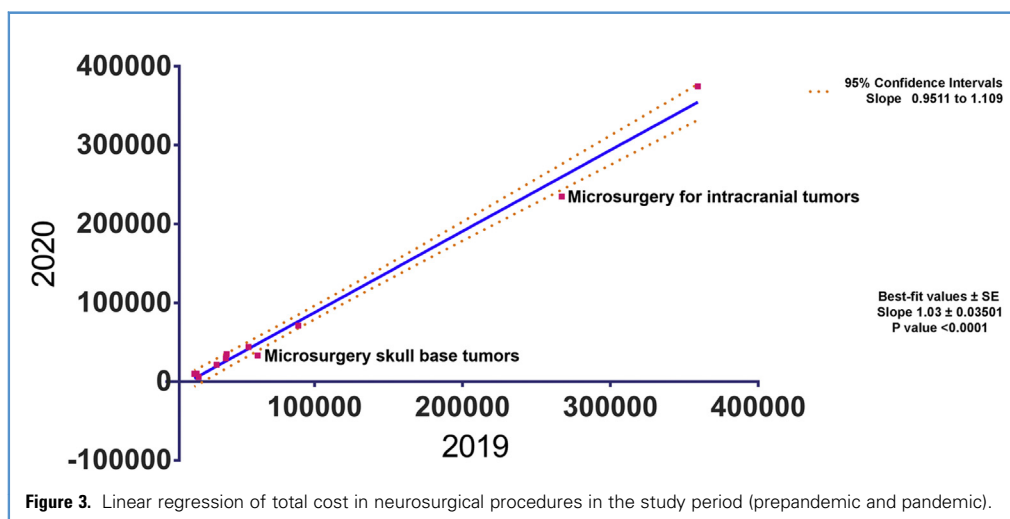


shifted to meet the emergency needs of COVID-19 patients and other emergent cases and the supply of resources is lacking in low- and middle-income regions. We observed a rise of the neurologic complications including cerebral vasospasm, lowered level of consciousness, refractory seizures, reoperations, hemiparesis, intraparenchymal hematoma, and systemic complications (i.e., nausea, vomiting, respiratory distress, hypotension, and infection of the surgical site) contributing to an increased mortality rate in our patients along the higher risk of SARS-CoV-2 infection in the hospital environment.¹³⁻¹⁵ The reduction in the number of elective neurosurgical procedures to minimize the exposure of fragile patients from COVID-19 and prioritization of patients requiring early surgical intervention lowered the number of neurosurgeons, operating rooms, and neurosurgery beds.

Neurosurgical Cases

In Brazil, we have had a reduction of 21.5% in all neurosurgery specialties and 14.89% in neurooncology procedures. Since the beginning of the COVID-19 pandemic, neurosurgery centers around the world have had to adapt additional layers of precautions to prevent new cases of COVID-19, resulting in a decrease in the overall number of neurosurgical procedures.^{2,9,10}

Elective surgeries have been postponed to minimize potential exposure of neurosurgical patients and health professionals with other comorbidities as recommended by neurosurgical societies and surgical colleges globally. The collaboration of neurosurgical societies will represent the key institutions for guiding the neurosurgical community to overcome the COVID-19 crisis and is also helpful for governments in planning and implementing new



management strategies for future medical epidemics and other disasters and for reorganizing neurosurgical care.¹⁶ These recommendations also involved redirection of resources and professionals to combat the pandemic.¹⁷ Surgeons are required to meet certain goals, such as reducing the risk of environmental contamination, minimizing exposure to the virus, and reducing the length of stay during the postoperative period, in emergency neurosurgery.¹⁸ This has decreased the ability to perform emergency surgeries in limited-resource settings. Moreover, social isolation may have contributed to the reduction in the number of neurosurgical emergencies via mitigation of common triggers, such as car accidents and cases of interpersonal violence.^{19,20}

Some studies observed that there were no significant changes in the distribution of the neurosurgery cases² as the number of procedures performed by all neurosurgical subspecialties decreased.²¹ Generally, most surgical departments in the world postponed elective surgery and evaluated on a case-by-case basis the risk of disease progression due to availability of other therapies including radiation and chemotherapy.² We observed a 51.52% reduction in microsurgical treatment of peripheral nerve tumor/neuroma. Peripheral nerve cases showed significantly fewer cases in the COVID-19 period than pre-COVID-19 period, which may be related to the fact that they are generally elective procedures and can be frequently postponed.² The procedures in our study that showed an increase or no change were the microsurgeries for intracranial tumor with complementary technique (4.79%) and microsurgery of spinal tumors with complementary technique (0%), indicating that prompt action in these procedures is necessary to clinical and functional deterioration, neurologic complications, compressive effects, or even death.^{15,20-27}

Economic Impact

We observed a total cost decrease of \$1,795,953.72 between 2019 and 2020. There was a \$45,985.34 cost reduction for elective cases, representing a reduction of -5.02%. This is consistent with the limited use of operating rooms and equipment for critical care and reduction of outpatient activity to redirect resources and decrease COVID transmission. Moreover, elective surgical cases have been canceled and standard treatments may therefore have been replaced by suboptimal treatment methods. In the case of the emergency total cost, we observed an \$88,988.97 reduction, accounting for a reduction of 0.5% compared with 2019.

In Brazil, the most significant total cost reduction was the microsurgical treatment of peripheral nerves (tumor/neuroma) with a 55% decrease overall and a decrease of 7.19% in the mean cost per procedure compared with the prepandemic period. This may be explained by the reduction of electives procedures following recommendations from professional societies and decreased demand for these procedures.²⁸ In our study, 2 neurosurgery procedures—microsurgery for skull base tumor and microsurgery for intracranial tumors—showed a total cost decrease higher than the estimate for the pandemic period, perhaps explained by a considerable reduction in hospitalizations.

However, the mean cost of these procedures showed an increase ($P = 0.0172$) due to limited resources, a lack of specialized neurosurgeons, need for a multidisciplinary team, and challenges

maintaining demand for a procedure with a difficult surgical approach.^{29,30} The cost of craniotomies also varies with patient factors such as age and comorbidities, as well as hospital factors such as teaching hospital status, hospital volume, and geographic region.³¹ We believe that we could extend these factors to other neurosurgical procedures, and they likely contributed to an increased mean cost per procedure in our cohort.

Furthermore, Brazil is a large country with socioeconomic discrepancies in the population of each region, leading to markedly varied levels of health and resources. Population disparities among regions on the basis of socioeconomic background compound issues resulting from access to and affordability of neurosurgical care related to the COVID-19 pandemic.^{1,32} Altered protocols to combat the dissemination of the virus and treat patients with COVID-19 may be particularly harmful to neurosurgical patients in regions with limited access to the health care system, leaving patients to die without proper resources to provide comprehensive care.^{16,33} The Southeast region has a high-volume regional medical center, in which 47.4% of total costs involved neurosurgery procedures in Brazil in 2020. The costs are higher at tertiary care centers with a facility for the management of complex neurosurgical diseases. However, high-volume centers are more cost-effective due to lower complication rates and more specialized care even in COVID-19 pandemic.^{21,34}

COVID-19 has significantly decreased surgical volume and revenue generation.³⁵ The lack of personal protective equipment and testing kits to prevent COVID-19 transmission and concomitantly increased demand has inflated the expenses in the hospitals. Moreover, these resources have been redistributed, restricting the ability of surgical specialties to function autonomously. In the case of neurosurgery, many procedures are dependent on the availability of ICU capacity for postoperative care.^{19,20} Decreased ICU capacity limits the ability to perform procedures and may also lead to increased costs through premature discharges or transfers.³⁶

Limitations

The DATASUS is a government database that compiles all data from the Brazilian Unified Health System (SUS) in public and private sectors. However, it depends on the proper filling of data by health professionals, potentially leading to inaccuracies. Some neurosurgical cases were considered neither elective nor emergency, preventing their inclusion in our calculation and decreasing the accuracy of the values that we report. The DATASUS does not provide some important information about patients' demographics, comorbidities, and symptoms or tumor type and location, surgery complications, and causes of mortality during hospitalization. Moreover, other procedures involving neurosurgery that were not included in the database were not considered in our statistical analysis.

CONCLUSION

The COVID-19 pandemic has decreased access to neurosurgery and the number of hospitalizations, prompted the creation of operational protocols to avoid viral transmission, and redirected resources and professionals to treat patients affected by the

pandemic. In Brazil, the COVID-19 pandemic has increased neurosurgical mortality, decreased neurosurgical hospitalizations, increased costs per procedure for a variety of neurosurgical procedures, and decreased overall neurosurgical costs as a result of the decreased hospitalizations. Our study serves as a stark example of the effect of the COVID-19 pandemic on neurosurgical care in settings of limited resources and access to care.

CRedit AUTHORSHIP CONTRIBUTION STATEMENT

Leonardo J.M. de Macêdo Filho: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Supervision, Project administration. **Ana**

Carolina A. Aragão: Investigation, Writing – original draft, Writing – review & editing. **Vito Thayson D. dos Santos:** Investigation, Writing – original draft, Writing – review & editing. **Lívia B.A. Galvão:** Investigation, Writing – original draft, Writing – review & editing. **Nathan A. Shlobin:** Investigation, Writing – review & editing. **Gaetano De Biase:** Writing – review & editing. **Paola Suarez-Meade:** Writing – review & editing. **Joao Paulo C. Almeida:** Writing – review & editing, Supervision, Project administration. **Alfredo Quinones-Hinojosa:** Writing – review & editing, Supervision, Project administration. **Lucas A.F. de Albuquerque:** Writing – review & editing, Supervision, Project administration.

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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.

Received 12 May 2021; accepted 6 August 2021

Citation: World Neurosurg. (2021) 155:e142-e149.
<https://doi.org/10.1016/j.wneu.2021.08.030>

Journal homepage: www.journals.elsevier.com/world-neurosurgery

Available online: www.sciencedirect.com

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