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The Impact of the Coronavirus Disease 2019 Pandemic on Neurosurgical Practice and Feasibility of Safe Resumption of Elective Procedures During this Era in a Large Referral Center in Tehran, Iran: An Unmatched Case-Control Study

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■ **OBJECTIVE:** The coronavirus disease 2019 (COVID-19) pandemic has considerably affected surgical practice. The present study aimed to investigate the effects of the pandemic on neurosurgical practice and the safety of the resumption of elective procedures through implementing screening protocols in a high-volume academic public center in Iran, as one of the countries severely affected by the pandemic.

■ **METHODS:** This unmatched case-control study compared 2 populations of patients who underwent neurosurgical procedures between June 1, 2019 and September 1, 2019 and the same period in 2020. In the prospective part of the study, patients who underwent elective procedures were tested for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection post-operatively to evaluate the viability of our screening protocol.

■ **RESULTS:** Elective and emergency procedures showed significant reduction during the pandemic (59.4%, $n = 168$ vs. 71.3%, $n = 380$) and increase (28.7%, $n = 153$ vs. 40.6%, $n = 115$, respectively; $P = 0.003$). The proportional distribution of neurosurgical categories remained unchanged during the pandemic. Poisson regression showed that the reduction in total daily admissions and some categories, including spine, trauma, oncology, and infection were

significantly correlated with the pandemic. Among patients who underwent elective procedures, 0 (0.0%) and 26 (16.25%) had positive test results on days 30 and 60 post-operatively, respectively. Overall mortality was comparable between the pre-COVID-19 and COVID-19 periods, yet patients with concurrent SARS-CoV-2 infection showed substantially higher mortality (65%).

■ **CONCLUSIONS:** By implementing safety and screening protocols with proper resource allocation, the emergency care capacity can be maintained and the risk minimized of hospital-acquired SARS-CoV-2 infection, complications, and mortality among neurosurgical patients during the pandemic. Similarly, for elective procedures, according to available resources, hospital beds can be allocated for patients with a higher risk of delayed hospitalization and those who are concerned about the risk of hospital-acquired infection can be reassured.

INTRODUCTION

The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) also known as coronavirus disease 2019 (COVID-19) is an ongoing pandemic that has imposed a huge burden on health care systems since its onset, worldwide.¹ The

Key words

- COVID-19
- Neurosurgery
- Pandemic
- SARS-CoV-2

Abbreviations and Acronyms

- CI:** Confidence interval
COVID-19: Coronavirus disease 2019
CT: Computed tomography
HRCT: High-resolution computed tomography
ICU: Intensive care unit
IQR: Interquartile range
IRR: Incidence rate ratio
OR: Odds ratio

RT-PCR: Reverse-transcriptase polymerase chain reaction

SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2

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increasing number of COVID-19 cases in addition to the need for care in patients with other medical conditions have resulted in major reorganizations within the health care system. In this regard, the COVID-19 pandemic has brought many challenges to surgical practice, such as the increasing economic demand resulting from the pandemic itself and the need to maintain surgical care in this circumstance.² Moreover, the risk of nosocomial spread of the virus has also raised concerns about elective procedures and hospitalizations during the pandemic. On the other hand, the delay in surgical management and treatment may result in clinical deterioration of patients with other conditions.³⁻⁵ Many guidelines have been published to prioritize elective procedures based on their level of urgency and postpone procedures with a lower risk for patients.⁶⁻¹⁰

At the time of writing (October 22, 2020), 41,121,120 COVID-19 cases had been reported worldwide, of which 545,286 cases including >31,000 deaths were confirmed in Iran, a large country in the Middle East with a population of 83 million people.^{11,12} The first COVID-19 cases in Iran were announced on February 19, 2020.¹³ Since then, new daily COVID-19 cases have begun to increase in Iran. After the second peak in new daily COVID-19 cases on June 4, 2020 (3574 patients), the trend in daily reported cases became steady, with an average of 2500 cases per day. However, on September 15, daily cases started to increase and on September 22, surpassed the number of cases in the second peak. Iran is passing the third peak and the number of new daily cases of COVID-19 is fluctuating around 5000 with daily deaths of >300.^{11,12} Since the start of the pandemic, Tehran, the nation's administrative as well as commercial capital, with a population of 8.7 million, has been one of the epicenters of COVID-19 in Iran, with >20,000 cases reported on August 3.¹⁴

Many previous studies from different countries, such as the United States, Italy, and Saudi Arabia, have reported the impact of the COVID-19 pandemic on neurosurgical practice and their experience during the pandemic. In this regard, these countries have shown a decline in the number of neurosurgical procedures during the COVID-19 pandemic period.¹⁵⁻²⁵ However, there is a lack of evidence regarding the effects of the pandemic on neurosurgical procedures in Iran. Furthermore, no study has prospectively assessed the postoperative infection status of patients undergoing elective neurosurgical procedures. In the present study, we assessed the differences in neurosurgical services between the COVID-19 and similar pre-COVID-19 periods in a high-volume academic neurosurgery center in Tehran, Iran. Further, we also prospectively examined the postoperative SARS-CoV-2 infection status of patients who underwent elective neurosurgical procedures in our center during the pandemic.

METHODS

Study Design and Setting

The present investigation was an unmatched case-control study aimed to assess the impact of the COVID-19 pandemic on neurosurgical practice in a large academic neurosurgical unit in Tehran, Iran. Shohadaye Tajrish Hospital is a high-volume academic public center providing care for northern, north-eastern, and eastern regions of Tehran province and city (covering >5.7 million inhabitants, with approximately 80% in Tehran city). All

neurosurgical procedures (both urgent and nonurgent) performed in the Department of Neurological Surgery at Shohadaye Tajrish Hospital from June 1, 2019, to September 1, 2019, and the same period in 2020, were included in this study. In addition, patients who underwent elective procedures within this period were prospectively evaluated for postoperative infection status. The study was approved by the institutional review board of Shahid Beheshti University of Medical Sciences. For the prospective part of the study, informed consent was obtained from all participants.

Data Sources and Variables

Data in the present study were retrospectively collected from the medical records of the Shohadaye Tajrish Hospital. Moreover, patients' postoperative SARS-CoV-2 infection status was assessed using the quantitative reverse-transcriptase polymerase chain reaction (RT-PCR) test of nasopharyngeal swabs 30 and 60 days postoperatively (preoperative negative RT-PCR and low-dose high-resolution computed tomography [HRCT] of the chest are required for elective inpatient admission in our center).²⁶ The information used in the study included age, sex, comorbidities, neurosurgical indication, length of hospital stay (days), length of intensive care unit (ICU) stay (days), SARS-CoV-2 infection status on days 30 and 60, and 30-day mortality. Day 30 was selected to assess the SARS-CoV-2 infection status related to the hospitalization (hospital-acquired COVID-19), and day 60 was selected to evaluate the out-of-hospital SARS-CoV-2 infection status (community-acquired COVID-19) of a cohort of patients who underwent elective neurosurgical procedures. Neurosurgical indications were classified into 8 categories (trauma, oncology, vascular, hydrocephalus, spine, infection, congenital, and others [functional and peripheral nerve]), which was similar to a previous report from Saudi Arabia.²⁴ The infection category included deep or superficial surgical site infections that require surgical debridement and intracranial infections that require prompt surgical drainage. The procedures in our study were divided into 3 subgroups based on their priority, which included emergency, semiurgent, and elective. However, for the purpose of analysis, both elective and semiurgent subgroups were considered as elective admissions. Details regarding the type of procedures and their subgroups including urgent, semiurgent, and elective are presented in [Table 1](#).

The computed tomography (CT) severity score in emergency patients with suspected or confirmed COVID-19 infection was also assessed in the present study.²⁷ The extent of involvement of each of the lung lobes was visually scored according to a 4-point scale as follows: 0, no involvement; 1, 1%–25% involvement; 2, 26%–49% involvement; 3, 50%–75% involvement; and 4, 76%–100% involvement. The final CT severity score (range, 0–20) included the sum of the lobar individual scores.

Statistical Analysis

Quantitative data were presented as mean \pm standard deviation or median with interquartile range (IQR). Qualitative data were reported as frequency and percentage. In the present study, patients in the COVID-19 and pre-COVID-19 periods were compared in terms of study variables. The Mann-Whitney U and independent t tests were used for comparing the nonparametric and parametric quantitative variables, respectively. Categorical variables were

Table 1. Intraoperative Measures, Types of Procedures (Priorities), and COVID-19 Operating Theater Characteristics

COVID-19 operating theater	<ol style="list-style-type: none"> 1) PPE: level 3 surgical gown, coveralls, filtering face piece 3 facial mask, 2 pairs of gloves, surgical hood, protective visors, goggles, waterproof boot and shoe cover 2) Powered air-purifying respirators was used in prolonged or high-risk operations 3) Patients' transfer from ward or ICU to OR was done by nurses in full PPE 4) OR staff were closely monitored and screened postoperatively 5) As minimum number of staff as possible were present in the OR
Intraoperative measures	<ol style="list-style-type: none"> 1) Disposable airway equipment was used 2) For patients who were preoperatively in the ICU, intubation was performed in the negative pressure ICU before surgery 3) For other patients, intubation/extubation was performed by anesthesiologist and at least 5 minutes before the other members enter the OR 4) Smoke evacuator was used whenever electrocautery was used 5) Any procedure that could possibly result in aerosol generation such as drilling was minimized 6) Endonasal approaches were avoided, patients were symptomatically managed, and surgery was postponed
Emergency (immediately)	
Trauma	<ol style="list-style-type: none"> 1) Decompressive craniectomy for acute traumatic brain injury 2) Traumatic intracranial hemorrhage (SAH, SDH, and epidural hematoma) 3) Depressed and open skull fractures 4) Acute increase in ICP 5) External ventricular drain placement and ICP monitoring in traumatic patients
Vascular	<ol style="list-style-type: none"> 1) Nontraumatic SAH and intracerebral hemorrhage (ruptured aneurysm or arteriovenous malformation) 2) Acute thrombectomy 3) Decompressive craniectomy for acute ischemic stroke
Oncology	<ol style="list-style-type: none"> 1) Tumors causing acute hydrocephalus and increase in ICP 2) Tumors causing acute visual impairment 3) Impaired level of consciousness caused by tumor 4) Tumors with increased risk of hemorrhage
Continues	

Table 1. Continued

Spine	1) Spinal cord compression caused by any disease presenting with acute or subacute neurologic deficit
Infection	<ol style="list-style-type: none"> 1) Deep or superficial surgical site infection that needs surgical debridement 2) Intracranial infections that require prompt surgical drainage
Others	<ol style="list-style-type: none"> 1) Acute traumatic peripheral nerve injury 2) Other complications such as cerebrospinal fluid leakage, instrument failure, and shunt malfunction
Semiurgent procedures (within 14 days)	
Vascular	<ol style="list-style-type: none"> 1) Unruptured aneurysm 2) Chronic SDH
Oncology	<ol style="list-style-type: none"> 1) Tumors causing acute and subacute neurologic deficits other than those mentioned in the emergency subgroup 2) Biopsy 3) High-grade tumors
Spine	1) Spinal cord compression caused by any disease presenting with subacute neurologic deficit
Elective procedures (>14 days)	1) Any procedure that was not emergency or semiurgent
PPE, personal protective equipment; ICU, intensive care unit; OR, operating room; SAH, subarachnoid hemorrhage; SDH, subdural hematoma; ICP, intracranial pressure.	

compared via a Fisher exact test and χ^2 test. Multivariate logistic regression (adjusted for age and sex) was performed to assess the differences in surgical categories and procedure types (emergency and elective) between the 2 periods using the odds ratios (ORs). Moreover, Poisson regression was used for the daily number of admissions in each surgical category to calculate the incidence rate ratios (IRRs) with 95% confidence intervals (CIs) and determine whether there is a significant correlation between the daily number of admissions and the COVID-19 pandemic period. Poisson regression included daily counts as the dependent response variable, with the year (study period), month, and day as the independent variables. A χ^2 goodness-of-fit test was used to check the goodness of fit of the Poisson regression model. All statistical analyses in the current study were conducted using R version 3.6.3 (R Foundation for Statistical Computing, Vienna, Austria). P values <0.05 were considered statistically significant.

RESULTS

A total of 816 procedures were performed, comprising 533 (65%) in the pre-COVID-19 period and 283 (35%) in the COVID-19 period. The mean ages of patients were 49.6 ± 17.4 years and 48 ± 16.2

Table 2. Demographic, Clinical, and Surgical Characteristics of Patients Undergoing Neurosurgical Procedures in pre-COVID-19 and COVID-19 Periods

	2019 (June 1–September 1)	2020 (June 1–September 1)	P Value
Number of admissions	533	283	
Elective, n (%)	380 (71.3)	168 (59.4)	0.001*
Emergency, n (%)	153 (28.7)	115 (40.6)	0.001*
Age (years), mean (standard deviation)	49.58 (17.35)	48.07 (16.2)	0.125
Sex, male, n (%)	312 (58.5)	180 (63.6)	0.229
Comorbidities, n (%)			
Hypertension	90 (16.9)	45 (15.9)	0.719
Diabetes mellitus	43 (8.06)	26 (9.2)	0.584
Coronary artery disease	25 (5.7)	16 (4.7)	0.549
Heart failure	6 (1.1)	3 (1)	0.932
Atrial fibrillation	6 (1.1)	2 (0.7)	0.721
Renal disease	1 (0.2)	0 (0.0)	1.000
Previous stroke	2 (0.4)	7 (2.5)	0.010*
Cancer	9 (1.7)	5 (1.8)	0.935
Chronic obstructive pulmonary disease	13 (2.4)	4 (1.4)	0.329
Length of hospital stay (days), median (IQR)	6 (4–10)	5 (3–7)	<0.001*
Length of ICU stay (days), median (IQR)			
Overall	6 (2.5–15)	9 (2.75–20.75)	0.455
COVID-19 ICU	—	10 (5.25–25.25)	0.388†
Non-COVID-19 ICU	—	8 (3–19)	—
Surgical categories, n (%)			
Trauma	78 (14.6)	50 (17.5)	0.267
Oncology	86 (16.1)	49 (17.1)	0.693
Spine	261 (48.9)	134 (47.5)	0.713
Vascular	51 (9.6)	27 (9.6)	0.990
Congenital	3 (0.6)	1 (0.4)	0.683
Hydrocephalus	11 (2.1)	4 (1.4)	0.510
Infection	23 (4.3)	8 (2.9)	0.290
Others	10 (1.9)	4 (1.4)	0.781
Complications	10 (1.9)	6 (2.1)	0.811
Spinal surgery indications, n (%)			
Degenerative disease (chronic neurologic deficit)	113 (21.2)	36 (12.7)	0.001*
Degenerative disease (acute/subacute neurologic deficit)	86 (16.1)	59 (20.9)	0.026*
Infection	10 (1.9)	6 (2.1)	0.746
Trauma	36 (6.8)	24 (8.5)	0.267
Tumor	16 (3.0)	9 (3.2)	0.806
SARS-CoV-2 infection status of elective procedures, n (%)			

IQR, interquartile range; ICU, intensive care unit; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

*Indicates statistically significant ($P < 0.05$).

†Compared with the non-COVID-19 intensive care unit.

Continues

Table 2. Continued

	2019 (June 1–September 1)	2020 (June 1–September 1)	P Value
At admission	—	0 (0.0)	—
Day 30	—	0 (0.0)	—
Day 60	—	26 (16.25)	—
Computed tomography severity score at admission, n (% of COVID-19 suspected patients)			
0 (none)	—	6 (12.5)	—
1–5 (minimal)	—	22 (45.8)	—
6–10 (mild)	—	9 (18.8)	—
11–15 (moderate)	—	7 (14.6)	—
16–20 (severe)	—	4 (8.3)	—
Mortality, n (%)	54 (10)	27 (9.5)	0.800

IQR, interquartile range; ICU, intensive care unit; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.
 *Indicates statistically significant ($P < 0.05$).
 †Compared with the non-COVID-19 intensive care unit.

years in the pre-COVID-19 and COVID-19 periods, respectively. Regarding sex, 312 (58.5%) and 180 (63.6%) patients were male in pre-COVID-19 and COVID-19 periods, respectively. Differences in comorbidities between the 2 periods are shown in [Table 2](#).

In terms of proportional distribution of surgical categories over the 3 months, no significant difference was found between the 2 periods using adjusted multivariate logistic regression. Both the percentage and absolute number of elective admissions over the 3 months decreased significantly during the COVID-19 period (59.4% of the total COVID-19 period cohort) compared with the pre-COVID-19 period (71.3% of the total pre-COVID-19 cohort) (OR, 0.62; 95% CI, 0.45–0.85; $P = 0.003$). The percentage of emergency admissions over the 3 months increased significantly during the COVID-19 period (40.6% of the total COVID-19 period cohort) compared with the pre-COVID-19 period (28.7% of the total COVID-19 period cohort) (OR, 1.60; 95% CI, 1.17–2.21; $P = 0.003$). [Table 3](#) shows the ORs for all surgical categories.

In addition to changes in the proportional distribution of neurosurgical categories over the 3 months in each study period, the effect of the COVID-19 pandemic on the rate of admissions per day was also assessed. There was a significant association between the reduction in the rate of total admissions per day and the COVID-19 pandemic period (IRR of study period, 0.55; 95% CI, 0.48–0.64; $P < 0.001$). There was also a significant association between the decrease in the daily number of admissions in both elective procedures (IRR of study period, 0.50; 95% CI, 0.42–0.59; $P < 0.001$) and emergency procedures (IRR of study period, 0.68; 95% CI, 0.52–0.87; $P = 0.002$) and the COVID-19 pandemic period. There was also a significant association between the decrease in the daily number of admissions in oncology (IRR of study period, 0.6; 95% CI, 0.39–0.91; $P = 0.017$), spine (IRR of study period, 0.51; 95% CI, 0.38–0.68; $P < 0.001$), trauma (IRR of study period, 0.63; 95% CI, 0.44–0.92; $P = 0.015$), and infection (IRR of study period, 0.31; 95% CI, 0.12–0.79; $P = 0.014$) categories and the COVID-19 period, according to the Poisson regression analysis. The daily number of admissions in other

categories including vascular, hydrocephalus, complications, congenital, and others (peripheral and functional), was also decreased; however, no statistically significant association was observed between the decline in their daily rates and the COVID-19 pandemic period ([Table 4](#)).

As previously mentioned, all inpatients who underwent elective surgery tested negative (RT-PCR test and low-dose HRCT of the chest) for SARS-CoV-2 preoperatively. Eight patients died before day 60 and were lost to follow-up. None of the 168 patients who underwent elective procedures (59.4% of the total COVID-19 period cohort) had positive test results on day 30 postoperatively. However, 26 patients (16.25% of the elective COVID-19 period cohort) had positive test results on day 60 postoperatively. All patients in this group had a length of hospital stay < 14 days (median, 6 days; IQR, 3–7.25 days). Among 115 patients who underwent emergency procedures (40.6% of the total COVID-19 period cohort), 48 (41.7% of the emergency COVID-19 period cohort) were suspected of having SARS-CoV-2 infection at admission. Among patients suspected of having SARS-CoV-2 infection, 9 (18.8% of COVID-19–suspected patients), 7 (14.6% of COVID-19–suspected patients), and 4 (8.3% of COVID-19–suspected patients) had mild, moderate, and severe CT severity score, respectively. The frequency and percentage of CT severity scores among the patients in this group are shown in [Table 2](#).

One of 2 hospital ICUs (a total of 32 beds) was changed into COVID-19 ICU with 12 beds. A new COVID-19 ICU was also set up in our institute, with a total of 15 beds. In pre-COVID-19 and COVID-19 periods 86 (16.1% of the total pre-COVID-19 period cohort) and 59 (20.8% of the total COVID-19 period cohort) patients were admitted to ICU, respectively ($P = 0.102$). Among the latter group, 23 patients (38.9% of the ICU admitted patients during the COVID-19 period) were admitted to the COVID-19 ICU. There was no significant difference in the length of ICU stay between the 2 periods ($P = 0.455$). Moreover, no significant difference in the length of ICU stays between the COVID-19 and non-COVID-19 ICUs was found during the pandemic ($P = 0.388$).

Table 3. Univariate and Multivariate Logistic Regression with Odds Ratio

	2019 (June 1–September 1), n (%)	2020 (June 1–September 1), n (%)	Odds Ratio (95% Confidence Interval)	P Value
Total	533	283	—	—
Univariate				
Trauma	78 (14.6)	50 (17.5)	1.25 (0.849–1.846)	0.267
Oncology	86 (16.1)	49 (17.1)	1.088 (0.741–1.599)	0.693
Spine	261 (48.9)	134 (47.5)	0.937 (0.702–1.251)	0.713
Vascular	51 (9.6)	27 (9.6)	0.997 (0.610–1.628)	0.990
Congenital	3 (0.6)	1 (0.4)	0.626 (0.065–6.050)	0.683
Hydrocephalus	11 (2.1)	4 (1.4)	0.680 (0.215–2.115)	0.510
Infection	23 (4.3)	8 (2.9)	0.645 (0.281–1.461)	0.290
Others	10 (1.9)	4 (1.4)	0.680 (0.215–2.156)	0.510
Complications	10 (1.9)	6 (2.1)	1.133 (0.407–3.150)	0.811
Elective procedures	380 (71.3)	168 (59.4)	0.588 (0.435–0.796)	0.001*
Emergency procedures	153 (28.7)	115 (40.6)	1.700 (1.256–2.299)	0.001*
Multivariate (adjusted for age and sex)				
Trauma	—	—	1.180 (0.790–1.761)	0.419
Oncology	—	—	1.092 (0.741–1.609)	0.658
Spine	—	—	0.968 (0.723–1.297)	0.829
Vascular	—	—	1.032 (0.630–1.962)	0.900
Congenital	—	—	0.571 (0.059–5.547)	0.629
Hydrocephalus	—	—	0.658 (0.206–2.100)	0.479
Infection	—	—	0.666 (0.294–1.512)	0.331
Others	—	—	0.653 (0.205–2.078)	0.471
Complications	—	—	1.164 (0.418–3.243)	0.771
Elective procedures	—	—	0.622 (0.451–0.852)	0.003*
Emergency procedures	—	—	1.607 (1.174–2.217)	0.003*

*Indicates statistically significant ($P < 0.05$).

The median length of hospital stay in the pre-COVID-19 period (6; IQR, 4–10) was significantly higher than the COVID-19 pandemic period (5; IQR, 3–7; $P < 0.001$). Mortality was similar in COVID-19 (10%) and pre-COVID-19 (9.5%; $P = 0.800$) periods. Among patients who were admitted to COVID-19 ICU, 15 (65.2% of the COVID-19 ICU admitted patients) died including 5 patients admitted because of intracerebral hemorrhage, 4 admitted because of subarachnoid hemorrhage, and 6 admitted because of head trauma. The mean age of this group was 55.7 ± 12.0 years.

DISCUSSION

According to the present study findings, a 46.9% decrease in the number of neurosurgical procedures was found in our center during 3 months in the COVID-19 pandemic period, which is similar to reports from other countries.^{23,24,28} Elective neurosurgical procedures were decreased by 55.8% in our study. In our institute,

national health care policies and guidelines have most likely resulted in this decline during the COVID-19 pandemic period, which is particularly evident in the initial 6 weeks of the study period (Figure 1). However, at week 7, because of the decrease in the number of COVID-19 cases and stable case rates after the second peak, the restrictions on the number of elective procedures were reduced, and the number of operations performed weekly was increased subsequently, yet it was still less than the number in the pre-COVID-19 period (Figure 1). Hence, it is likely that other factors such as patients' concerns about seeking medical care, fear of infection during the pandemic, and lack of enough resources (to provide both COVID-19 and non-COVID-19 care) contributed to this decrease (compared with the pre-COVID-19 period) during the last 6 weeks of the study. Similarly, previous surveys have also reported a higher role for national restrictions in decreased surgical volume.^{17,28–31} Multivariate analysis also showed that the distribution pattern was changed substantially, with a

Table 4. Incidence Rate Ratios with 95% Confidence Interval Calculated by Poisson Regression

	P Value of Year/Study Period	Year/Study Period IRR	Month IRR	Day IRR
Overall	<0.001*	0.553 (0.478–0.641)	1.035 (0.949–1.128)	1.010 (1.002–1.018)
Elective procedures	<0.001*	0.500 (0.417–0.598)	1.028 (0.926–1.141)	1.009 (0.999–1.018)
Emergency procedures	0.002*	0.675 (0.524–0.870)	1.036 (0.890–1.207)	1.013 (0.999–1.027)
Trauma	0.015*	0.635 (0.440–0.915)	1.025 (0.824–1.275)	1.003 (0.984–1.024)
Oncology	0.005*	0.600 (0.419–0.858)	0.899 (0.727–1.113)	1.008 (0.989–1.028)
Spine	<0.001*	0.539 (0.438–0.664)	1.177 (1.041–1.330)	1.015 (1.004–1.027)
Vascular	0.062	0.574 (0.357–1.066)	0.903 (0.682–1.195)	1.017 (0.992–1.044)
Congenital	1.000	1.00 (0.062–15.98)	1.00 (0.183–5.459)	0.885 (0.719–1.090)
Hydrocephalus	0.372	0.571 (0.167–1.952)	1.523 (0.715–3.244)	0.965 (0.902–1.033)
Infection	0.014*	0.315 (0.126–0.790)	0.941 (0.582–1.522)	0.998 (0.955–1.042)
Others	0.083	0.363 (0.115–0.1.141)	0.737 (0.391–1.390)	0.975 (0.920–1.032)
Complications	0.323	0.600 (0.218–1.650)	0.828 (0.452–1.517)	1.010 (0.956–1.067)

Number of daily admissions as the response variable; month, day, and year as the independent variables. Year variable represents the COVID-19 and pre-COVID-19 periods.

IRR, incidence rate ratio.

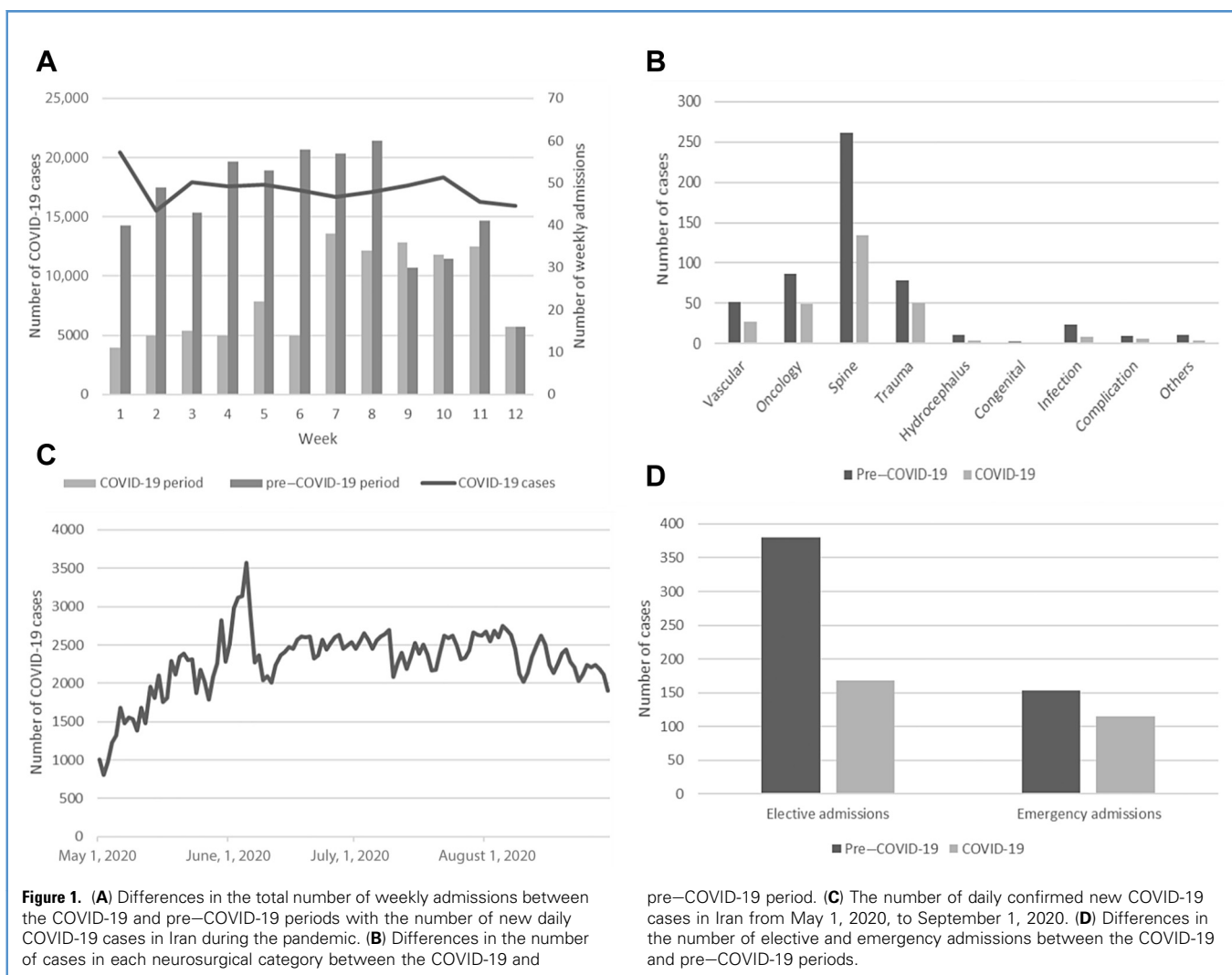
*Indicates statistically significant ($P < 0.05$).

significant increase in the proportion of emergency procedures during the pandemic. This increase was mainly caused by a considerable decline in elective procedures, which was also reported in previous studies. Bajunaaid et al.²⁴ in a previous study from Saudi Arabia showed a significant increase in the percentage of cases with priority 1 including urgent procedures. Similarly, Patel et al.²⁵ reported a 42% decrease in adult procedures with significant reductions in the spine and endovascular categories. However, procedures related to trauma remained unchanged in these categories.

No changes were also observed in the pattern of distribution of surgical categories. The percentage of all categories except for oncology and trauma was decreased during the pandemic, which was not significant. A similar or higher number of neuro-oncology cases during the pandemic compared with the same period in the previous year has been reported previously.³² Although our oncology group's proportion (OR, 1.09; 95% CI, 0.74–1.61) was increased, the absolute number of cases was decreased. After the risk assessment of oncology patients in our center, depending on the underlying disease, they were assigned to undergo either urgent or nonurgent surgery. Nevertheless, none of the procedures in this category was postponed for more than 21 days in our center. Therefore, it is unlikely that our triage system has resulted in this decline. Difficulties in access to radiology facilities during the pandemic and patients' concerns regarding seeking care may have contributed mostly to this pattern. In this regard, a previous report from Italy³² showed a higher ratio for emergency neuro-oncology cases, with an increased number of total neuro-oncology cases. The same was observed for trauma cases (OR, 1.18; 95% CI, 0.79–1.76). This situation was mainly caused by a significant decrease in the number of elective procedures resulting from national guidelines that have been shown previously.^{17,24,25,33} The percentage of the

vascular category remained unchanged during the pandemic (OR, 1.03; 95% CI, 0.63–1.96), whereas the absolute number of admissions over the 3 months decreased. The main reason for the reduction in the total number of vascular cases may be the decline in procedures with a more elective nature, such as endovascular procedures, open surgery for unruptured intracranial aneurysms or arteriovenous malformations, and carotid endarterectomy. The remaining vascular cases mostly consisted of indications with the more severe onset of symptoms. The total number of spinal procedures decreased from 261 to 133 and their percentage also decreased, although it was not significant (OR, 0.97; 95% CI, 0.72–1.29). Among the spine subgroups, there was a significant increase in the percentage of degenerative cases with severe acute and subacute neurologic deficits. However, degenerative indications with chronic and less severe deficits were significantly decreased. Other spine indications including trauma, tumor, and infection were unchanged during the pandemic. These findings are consistent with previous reports.^{8,15,34–37} Patel et al.²⁵ showed a significant decrease in weekly performed spine procedures, with trauma-related spine procedures unchanged during the pandemic.

A significant decline in the number of daily admissions was found for all procedures as well as spine, oncology, trauma, and infection categories during the COVID-19 pandemic period using Poisson regression. Similarly, previous reports have also shown a significant decrease in the weekly number of procedures. One of the main reasons for this decline is the decrease in the number of elective procedures, which is strongly implied by the reduced number of daily admitted cases in the spine category. Moreover, the substantial burden imposed by the pandemic mandates the need for reallocation of resources such as radiology facilities, ICUs, and medical staff, which has resulted in major reorganizations in the health care system.^{18,21,32,34} This situation may also have



contributed to the decrease in the daily incidence of admissions in all categories because our institute is one of the major centers responsible for COVID-19 care and admits both COVID-19-positive and COVID-19-negative patients (separate departments with isolated facilities dedicated to COVID-19 care). In this respect, our center has faced some challenges during the COVID-19 pandemic period, including the need for sharing limited available resources, which mostly involved workforce and imaging facilities. Workforce shortage in our center was mainly caused by task sharing and shifting implemented to allow for more efficient care for both patients with COVID-19 and those with other medical conditions. Consequently, this might have been one of the factors that hindered us from reaching the optimal number of elective procedures performed weekly after week 7 of our study. Regarding trauma cases, one of the potential causes may be the decreased number of traffic-related or work-related accidents because of the pandemic. Lubansu et al.²³ found a substantial reduction in the number of trauma-related procedures. Similarly, in the study conducted by Jayakumar et al.,³⁸ the number of traumatic brain injuries was significantly

decreased. However, Patel et al.²⁵ showed that the number of trauma-related procedures remained unchanged during the pandemic. Further, the number of admissions in the infection category was also decreased significantly during the pandemic. There are some potential explanations for this finding, including the hospital restrictions on the number of visitors, increased use of personal protective equipment among health care personnel as an indirect effect of the pandemic, and the decline in the number of operations.³⁹ We also found a significantly lower length of hospital stay during the pandemic, which was largely the result of hospital policies for minimizing this time, especially in elective procedures.

In addition, patients who underwent elective procedures were prospectively followed up and none showed positive test results within 30 days postoperatively. Among those who were tested positive at day 60 postoperatively, none was hospitalized for more than 14 days. Therefore, it is unlikely that they became infected in the hospital. To our knowledge, the present study is the first to prospectively assess the SARS-CoV-2 infection status of patients undergoing elective neurosurgical procedures in a high-volume

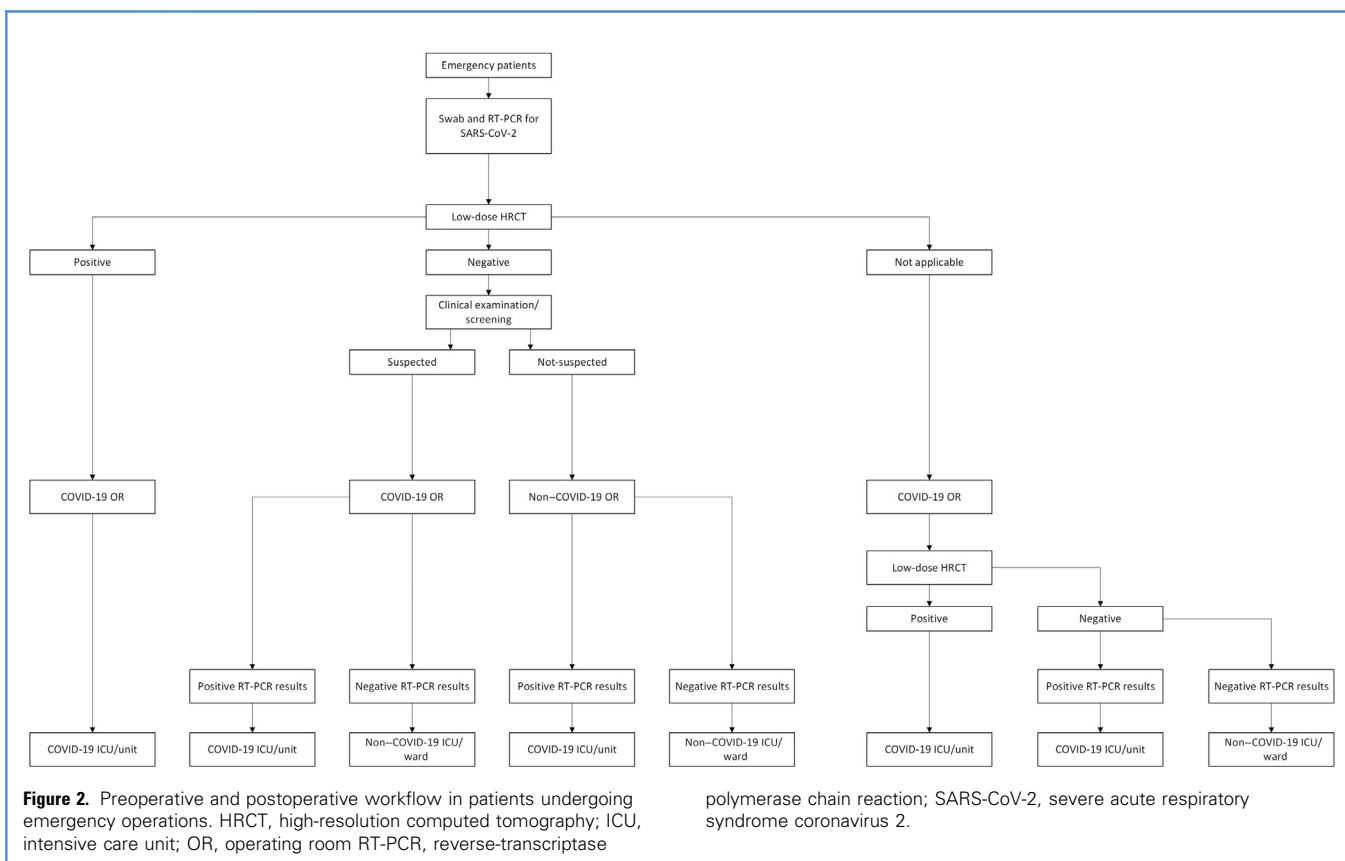
COVID-19 care center. Concerning the neurosurgical practice, 1 previous report examined 154 patients retrospectively, of whom 5 tested positive for SARS-CoV-2 within 30 days postoperatively.²³ Gammeri et al.⁴⁰ in a prospective observational study from the United Kingdom found that among 309 patients undergoing elective general surgery, only 1 tested positive after the surgery in a COVID-19-free hospital. Many measures were taken in our center to prevent the risk of COVID-19 infection during hospitalization and operation. All medical staff in our ward were assigned into smaller teams, and shifts were reorganized to cover the patients to the greatest extent possible and to reduce the risk of infection. For residents' training, tele-education and video conferencing were used and only senior trainees were allowed to be directly involved in care delivery and procedures. Regular personnel screening for symptoms was performed and in cases of suspicion, the staff were tested and isolated if there were positive test results. Preoperative RT-PCR and low-dose HRCT of the chest were performed for all inpatients who underwent elective procedures and only negative patients were admitted (results within 72 hours before the operation). Our workflow in the management of patients with positive results is shown in Figures 2 and 3. One operating theater and 2 ICUs was devoted to care of patients with COVID-19. Safety measures for the COVID-19 operating theater are listed in Table 1.

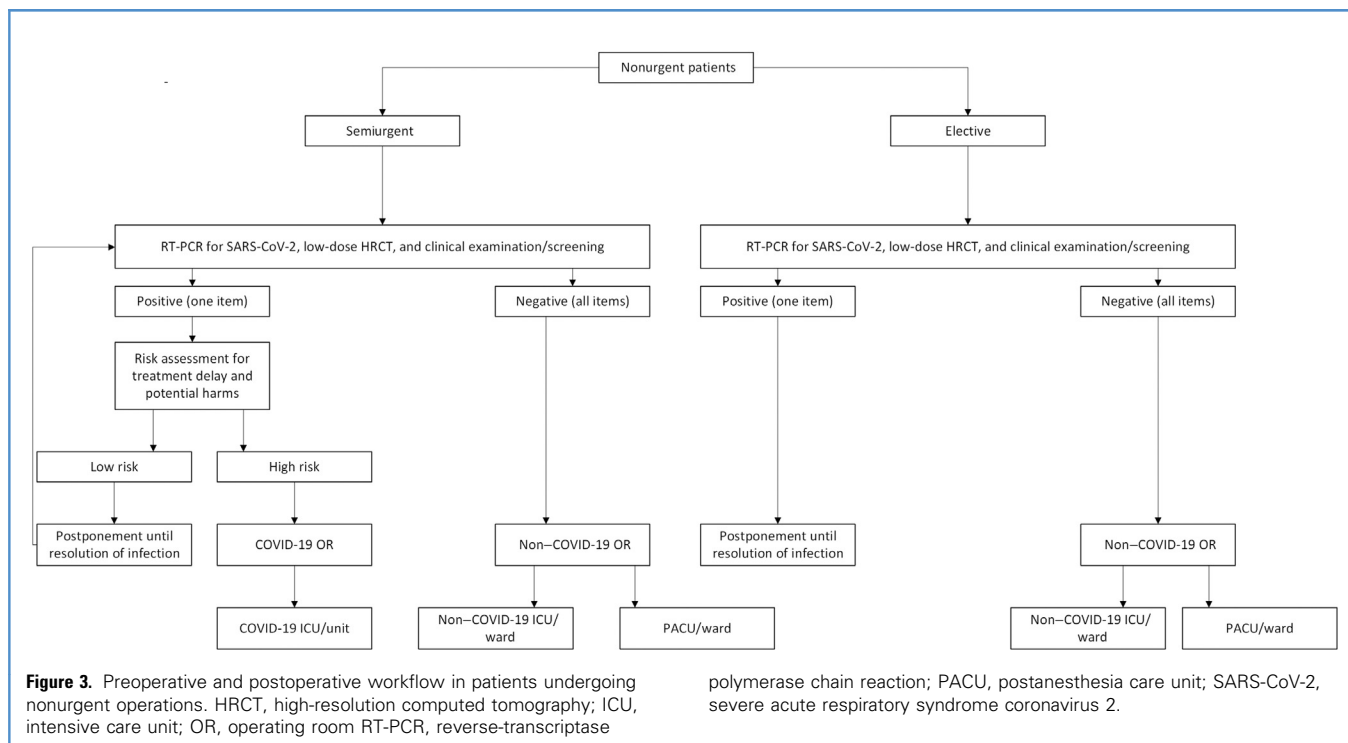
During our study period, 15 patients with COVID-19 infection were admitted to the COVID-19 ICU, with mortality of 65.2%.

Panciani et al.⁴¹ in a previous case series showed mortality of 80.0% in patients with chronic subdural hematoma and COVID-19 infection. In that report, the patient treated conservatively survived whereas the others, who underwent surgical procedures, died. Lubansu et al.²³ showed mortality of 45% in their COVID-19 cohort. The mortality of patients who underwent neurosurgical procedures was 77%. Previous studies have also shown higher mortality in patients with perioperative COVID-19 infection undergoing surgery.^{42,43} However, there is still a need for further evidence regarding the management and outcome of COVID-19-infected neurosurgical patients.

Strengths and Limitations

The present study has some limitations that have to be considered. First, the groups (pre-COVID-19 and COVID-19 periods) in this study were not matched for the potential confounding variables. Second, this study is limited to 1 center and may not be representative of the population. Hence, future multicenter or nationwide studies are needed to assess the changes in neurosurgical practice during the COVID-19 pandemic period in Iran. Third, the day-30 RT-PCR test may have missed some of the COVID-19-positive cases under the assumption that they had become infected during hospitalization and recovered from the disease before day 30, and this is a potential source of bias accordingly. Besides, in the case of COVID-19 infection, patients must have been asymptomatic or presymptomatic at discharge because none of the patients





who underwent elective procedures developed COVID-19-related symptoms during their hospital stay. Patients were also interviewed on day 30, and none reported the development of COVID-19-related symptoms during the period between their discharge and the day-30 RT-PCR test. Nevertheless, the findings of the present study should be interpreted in light of these limitations. Despite the limitations, this study has significant strengths. First, to our knowledge, the present study is the first to prospectively evaluate the infection status of patients undergoing elective neurosurgical procedures before the operation and twice postoperatively. These findings provide new pieces of evidence regarding the resumption of the elective neurosurgical procedures during the COVID-19 pandemic in the future. Second, this study was performed in a high-volume academic public center that is also one of the major COVID-19 care centers in Tehran, Iran, with a relatively large sample size. Furthermore, this study covers the period between June 1, 2020, and September 1, 2020, which includes the second peak in the number of daily new cases in Iran.^{11,12} As of October 22, 2020, Iran was passing the third peak with new daily cases of >5000, new daily deaths of >300, and 4895 critical COVID-19 cases. However, our experience in this period will be assessed in a future work.

CONCLUSIONS

The present investigation provided useful information regarding the safety of the resumption of elective procedures and the changed pattern of neurosurgical care during the COVID-19

pandemic. We believe that our findings might aid other centers in providing optimal neurosurgical care while facing the challenges posed by the COVID-19 pandemic (e.g., the need for allocating available resources including imaging facilities, ICUs, beds, and workforce to cover both COVID-19 and non-COVID-19 cares). The present study had some key findings. The results of the prospective part of the study suggested that elective neurosurgical procedures could be resumed safely during this era. We also provided our safety measures with both emergency and nonurgent management workflows, which could be implemented by other institutes or assist in development of future guidelines. Moreover, based on our results concerning the changed composition of neurosurgical practice, we can conclude that proper resource allocation and reorganizations in workflow increase the neurosurgical care capacity, yet we did not reach the optimal number of elective procedures. In addition, although the restrictions on elective procedures were reduced in our center, the percentage and the absolute number of elective procedures in the COVID-19 period were still significantly less than during the pre-COVID-19 period, which is likely the result of patients' concerns and lack of sufficient resources. Thus, patients with various neurosurgical conditions should be informed of the importance of seeking medical care during the pandemic.

CRedit AUTHORSHIP CONTRIBUTION STATEMENT

Roozbeh Tavanaei: Conceptualization, Methodology, Software, Formal analysis, Writing – original draft. **Pooria Ahmadi:**

Investigation, Data curation, Writing — original draft. **Kaveh Orafi Yazdani:** Investigation, Data curation, Writing — original draft. **Alireza Zali:** Validation, Investigation, Supervision, Resources,

Project administration, Writing — review & editing. **Saeed Oraee-Yazdani:** Conceptualization, Methodology, Supervision, Resources, Writing — review & editing.

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