

Minerva Access is the Institutional Repository of The University of Melbourne

Author/s:

Nogueira, RG;Abdalkader, M;Qureshi, MM;Frankel, MR;Mansour, OY;Yamagami, H;Qiu, Z;Farhoudi, M;Siegler, JE;Yaghi, S;Raz, E;Sakai, N;Ohara, N;Piotin, M;Mechtouff, L;Eker, O;Chalumeau, V;Kleinig, TJ;Pop, R;Liu, J;Winters, HS;Shang, X;Vasquez, AR;Blasco, J;Arenillas, JF;Martinez-Galdamez, M;Brehm, A;Psychogios, MN;Lylyk, P;Haussen, DC;Al-Bayati, AR;Mohammaden, MH;Fonseca, L;Luís Silva, M;Montalverne, F;Renieri, L;Mangiafico, S;Fischer, U;Gralla, J;Frei, D;Chugh, C;Mehta, BP;Nagel, S;Mohlenbruch, M;Ortega-Gutierrez, S;Farooqui, M;Hassan, AE;Taylor, A;Lapergue, B;Consoli, A;Campbell, BC;Sharma, M;Walker, M;Van Horn, N;Fiehler, J;Nguyen, HT;Nguyen, QT;Watanabe, D;Zhang, H;Le, HV;Nguyen, VQ;Shah, R;Devlin, T;Khandelwal, P;Linfante, I;Izzath, W;Lavados, PM;Olavarría, VV;Sampaio Silva, G;de Carvalho Sousa, AV;Kirmani, J;Bendszus, M;Amano, T;Yamamoto, R;Doijiri, R;Tokuda, N;Yamada, T;Terasaki, T;Yazawa, Y;Morris, JG;Griffin, E;Thornton, J;Lavoie, P;Matouk, C;Hill, MD;Demchuk, AM;Killer-Oberpfalzer, M;Nahab, F;Altschul, D;Ramos-Pachón, A;Pérez de la Ossa, N;Kikano, R;Boisseau, W;Walker, G;Cordina, SM;Puri, A;Luisa Kuhn, A;Gandhi, D;Ramakrishnan, P;Novakovic-White, R

Title:

Global impact of COVID-19 on stroke care

Date:

2021-07-01

Citation:

Nogueira, R. G., Abdalkader, M., Qureshi, M. M., Frankel, M. R., Mansour, O. Y., Yamagami, H., Qiu, Z., Farhoudi, M., Siegler, J. E., Yaghi, S., Raz, E., Sakai, N., Ohara, N., Piotin, M., Mechtouff, L., Eker, O., Chalumeau, V., Kleinig, T. J., Pop, R. ,... Novakovic-White, R. (2021). Global impact of COVID-19 on stroke care. *International Journal of Stroke*, 16 (5), pp.573-584. <https://doi.org/10.1177/1747493021991652>.

Persistent Link:

<https://hdl.handle.net/11343/274003>

License:

CC BY

Global impact of COVID-19 on stroke care

SVIN COVID-19 global registry

International Journal of Stroke
0(0) 1–12
© 2021 World Stroke Organization
 Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/1747493021991652
journals.sagepub.com/home/wso



Abstract

Background: The COVID-19 pandemic led to profound changes in the organization of health care systems worldwide.

Aims: We sought to measure the global impact of the COVID-19 pandemic on the volumes for mechanical thrombectomy, stroke, and intracranial hemorrhage hospitalizations over a three-month period at the height of the pandemic (1 March–31 May 2020) compared with two control three-month periods (immediately preceding and one year prior).

Methods: Retrospective, observational, international study, across 6 continents, 40 countries, and 187 comprehensive stroke centers. The diagnoses were identified by their ICD-10 codes and/or classifications in stroke databases at participating centers.

Results: The hospitalization volumes for any stroke, intracranial hemorrhage, and mechanical thrombectomy were 26,699, 4002, and 5191 in the three months immediately before versus 21,576, 3540, and 4533 during the first three pandemic months, representing declines of 19.2% (95%CI, –19.7 to –18.7), 11.5% (95%CI, –12.6 to –10.6), and 12.7% (95%CI, –13.6 to –11.8), respectively. The decreases were noted across centers with high, mid, and low COVID-19 hospitalization burden, and also across high, mid, and low volume stroke/mechanical thrombectomy centers. High-volume COVID-19 centers (–20.5%) had greater declines in mechanical thrombectomy volumes than mid- (–10.1%) and low-volume (–8.7%) centers ($p < 0.0001$). There was a 1.5% stroke rate across 54,366 COVID-19 hospitalizations. SARS-CoV-2 infection was noted in 3.9% (784/20,250) of all stroke admissions.

Conclusion: The COVID-19 pandemic was associated with a global decline in the volume of overall stroke hospitalizations, mechanical thrombectomy procedures, and intracranial hemorrhage admission volumes. Despite geographic variations, these volume reductions were observed regardless of COVID-19 hospitalization burden and pre-pandemic stroke/mechanical thrombectomy volumes.

Keywords

COVID-19, stroke care, acute ischemic stroke, mechanical thrombectomy, intracranial hemorrhage, epidemiology

Received: 16 December 2020; accepted: 8 January 2021

Introduction

In December 2019, a novel highly pathogenic virus, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), caused an infectious disease involving multiple organ systems termed coronavirus disease 2019 (COVID-19). COVID-19 holds a unique balance between high transmissibility and low-to-moderate morbidity and mortality that has led to a nearly universal spread with devastating consequences worldwide. On 11 March 2020, the World Health Organization declared a global pandemic as COVID-19 hospitalizations and emergency medical system activations increased. As a potential consequence of its neurotropism as well as the inflammatory,

immunological, and coagulation disorders, COVID-19 has been reported in association with a broad array of neurological disorders including encephalitis, Guillain-Barre syndrome, seizures, ischemic, and hemorrhagic strokes.¹ Some groups reported an increase in cryptogenic strokes involving young patients with SARS-CoV-2 infection, possibly in association with endothelial inflammation and thrombotic diathesis.^{2–7} Others reported a decline in the rates of stroke hospitalizations and the proportion of patients receiving

Corresponding author:

Thanh N. Nguyen, Boston Medical Center, Boston University School of Medicine, Boston, MA 02118, USA.
Email: thanh.nguyen@bmc.org

reperfusion therapies (intravenous thrombolysis (IVT) and/or mechanical thrombectomy (MT)) for acute ischemic stroke (AIS). Notably, many of these studies originated from global epicenters for the pandemic supporting the notion that the indirect or collateral damage of COVID-19 on systems of care has had a greater impact on stroke patients than the viral infection itself.^{3,5,8–12} However, most of these reports were limited to regional or country-specific analyses, and thus, the extent to which the COVID-19 outbreak has impacted global stroke systems of care has not been previously assessed. Importantly, given the profound benefit of MT in AIS, the global public health impact of such declines, if confirmed, adds to the devastation caused by COVID-19.

Aims and hypotheses

We conducted an international, observational study on the impact of the COVID-19 pandemic on stroke care at the height of the COVID-19 pandemic. Our primary aim was to evaluate the effect of COVID-19 on stroke care as measured by the changes in volumes for overall stroke hospitalizations, ischemic stroke/transient ischemic attacks (TIA) admissions, ICH admissions, and MT procedures across the pre-pandemic and pandemic periods in a multinational pool of comprehensive stroke centers (CSC). The study compared the three initial months of the pandemic (1 March 2020–31 May 2020) with (1) the immediately preceding months (December 2019–February 2020 for overall volume and November 2019–February 2020 for monthly volume) as the primary analysis and (2) the equivalent three months in the previous year (1 March 2019–30 May 2019) as the secondary analysis. The reason for this analytic hierarchy was an a priori expectation that the volumes for both stroke admissions and MT procedures would increase over time due to the growing evidence supporting the broader utilization of MT.^{13–15} While the primary analysis provided a realistic picture of stroke care utilization prior to COVID-19, the secondary analysis allowed for the assessment for potential seasonal variations.¹⁶

We hypothesized that in the face of the pandemic's strain on healthcare infrastructure, (1) a reduction in all four aforementioned measurements of stroke care would take place over the pandemic, (2) centers with higher COVID-19 inpatient volumes would report greater decreases in stroke admissions and MT procedure volumes, (3) the degree of decline in stroke admissions and MT procedure volumes would be less profound in high-volume compared to low-volume stroke centers, and (4) a geographic variation would exist in the intensity of decline in stroke care.

Methods

Data are available upon request to the corresponding author.

Study design

This was a cross-sectional, observational, retrospective study evaluating monthly and weekly volumes of consecutive patients hospitalized with a diagnosis of COVID-19, stroke, MT, and ICH. The diagnoses were identified by their related ICD-10 codes (primary, secondary, or tertiary discharge codes) and/or classifications in stroke databases at participating centers.

Setting and participants

Data were collected from collaborators of the Society of Vascular and Interventional Neurology, the Middle East North Africa Stroke and Interventional Neurotherapies Organization, the Japan Society of Vascular and Interventional Neurology, and academic partners from 6 continents, 40 countries, and 187 CSCs. To reduce bias, only centers providing the full dataset required for any given analysis were included in that specific analysis. Centers were screened for potential confounders that could explain unexpected changes in volumes. One center in Vietnam was excluded from the MT secondary analysis due to an abrupt increase in volume attributed to the purchase of automated imaging software. One center in Brazil was excluded from the stroke admission analysis because it became the designated center for stroke patients, resulting in tripling of their volumes.

Study variables and outcomes measures

The overall and mean monthly volumes for stroke hospitalizations, admissions for ischemic stroke/TIA, and admissions for ICH and MT procedures were compared across the pandemic and pre-pandemic periods for the overall population and across the low, mid, and high volume strata based on mean monthly volume tertiles for COVID-19 hospitalizations (≤ 10.6 vs. >10.6 – 103.6 vs. >103.6 COVID-19 admissions/month), stroke admissions (≤ 46.2 vs. >46.2 – 78.4 vs. >78.4 stroke admissions/month), and MT interventions (≤ 4.8 vs. >4.8 to 11.4 vs. >11.4 procedures/month).

Statistical analysis

We first compared overall hospital volumes for stroke admissions (overall stroke, ischemic, and ICH) and MT procedures between the pre-pandemic and the pandemic period. For this analysis, the percentage change in the number of admissions or procedures between the

two time periods was calculated. The three-month pre-pandemic period was restricted to three months before the pandemic (1 December 2019–29 February 2020) to keep it consistent with the three months during the COVID-19 pandemic group (1 March 2020–31 May 2020). The 95% confidence intervals for percentage change were calculated using the Wilson procedure without continuity correction. The analyses were repeated within each tier (low, mid, and high) of centers classified based on COVID-19 hospitalizations, stroke admissions, and MT procedures. The relative percentage change in overall volume between low, mid, and high-volume centers was tested using the *z*-test of proportion. We also looked at relative change in overall volume by continent.

In the second analysis, we compared monthly hospital volumes (admissions or procedures/hospital/month) for our outcome of interests between the pre-pandemic and the pandemic period. For the pre-pandemic period, for each hospital, the monthly hospital volume was calculated from November 2019 to February 2020 and compared to the monthly hospital volume during the pandemic period (1 March 2020–31 May 2020). The data were analyzed in a mixed design using a repeated-measures analysis of variance (PROC MIXED analysis in SAS) to account for the paired data structure and potential covariates. The auto-regressive, compound symmetrical, and unstructured variance-covariance matrix structures were analyzed for the best model determined by Akaike's Information Criterion. The unstructured matrix was the best fit and used for most analyses. The monthly hospital volume analysis was adjusted for peak COVID-19 volume for each country and the continent. Estimated marginal means were calculated using the LSMEANS statement in PROC MIXED. Similar to the overall volume analysis, monthly volume analysis was repeated within low, mid, and high tier of centers based on their COVID-19 hospitalizations, stroke admissions, and MT procedures as well as by the continent.

Finally, for our secondary objective, we compared the relative change in overall volume and change in monthly hospital volume during the COVID-19 pandemic and corresponding three months from 2019 (1 March 2019–31 May 2019). All data were analyzed using SAS version 9.4 (SAS Institute), and the significance level was set at a *p*-value of <0.05.

Funding and ethics

This was an investigator-initiated project with no funding. The first and last authors wrote the first draft of the manuscript with subsequent input of all co-authors. The institutional review boards from the coordinating sites (Emory University and Boston University)

considered that the investigators did not have access to protected health information, and thus no IRB oversight was required since the study did not meet the federal description of human subject research. This study is reported in accordance with the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) statement.

Results

A total of 16,141, 26,699, and 21,576 stroke hospitalizations (overall *n* = 64,416) and 3397, 5191, and 4533 MT procedures (overall *n* = 13,121) were included across the three-month prior year, three-month immediately pre-pandemic, and three-month pandemic periods, respectively.

Overall stroke hospitalization volumes

In the primary analysis of overall volume, stroke hospitalization volumes were 26,699 admissions in the three months immediately before compared to 21,576 admissions during the pandemic, representing a 19.2% (95%CI, −19.7 to −18.7, *N* = 121 sites) drop, Table 1. The stroke hospitalization decline had a geographic variation: Asia, −20.5% (95%CI, −21.2 to −19.8); North America, −20.6% (95%CI, −21.4 to −19.7); Europe, −11.2% (95%CI, −12.3 to −10.1); South America, −15.9% (95%CI, −17.9 to −14.0); Oceania, −11.6% (95%CI, −14.4 to −9.3); Africa, −48.1% (95%CI, −55.8 to −40.5), Table S1. In an analysis of monthly volume, after adjustment for peak COVID-19 volume by country and continent, the number of hospitalizations for stroke/month/hospital (adjusted mean (SE)) declined from 76.4 (12.3) pre-pandemic to 64.2 (12.0) during the pandemic (*p* < 0.0001), Table 1.

Mechanical thrombectomy procedural volumes

MT volume data was represented by 176 centers in the primary analysis with 5191 procedures in the three months immediately preceding compared to 4533 procedures during the first three months of the pandemic, representing a 12.7% (95%CI, −13.6 to −11.8) decline, Table 2. The volume reduction varied: Asia, −9.8% (95%CI, −11.3 to −8.4); North America, −14.5% (95%CI, −16.2 to −12.9); Europe, −14.4% (95%CI, −16.4 to −12.6); South America, −12.4% (95%CI, −19.0 to −7.9), Oceania, −9.4% (95%CI, −13.4 to −6.5); Africa, −21.2% (95%CI, −37.8 to −10.7), Table S2. The adjusted mean (SE) number of MT procedures/month/center decreased from 10.9 (1.3) pre-pandemic to 9.8 (1.3) during the pandemic (*p* < 0.0001), Table 2. There were 120 centers that

Table 1. Stroke admissions overall and monthly volumes immediately before and during the COVID-19 pandemic

	Overall volume				Monthly volume ^a			
	N	n1	n2	Change % (95%CI)	N	Immediately before Adjusted mean (SE)	During COVID-19	p
Overall	119	26,699	21,576	-19.2 (-19.7 – -18.7)	121	76.4 (12.3)	64.2 (12.0)	<0.0001
Hospital COVID-19 volume ^b								
Low	38	7612	6654	-12.6 (-13.4 – -11.9)	38	62.4 (31.4)	53.9 (30.7)	0.002
Mid	31	7495	6008	-19.8 (-20.8 – -19.0)	34	84.8 (10.5)	71.0 (8.7)	0.002
High	30	7163	5534	-22.7 (-23.7 – -21.8)	33	90.1 (9.8)	72.9 (9.3)	<0.0001
Hospital stroke volume ^c								
Low	40	3536	3003	-15.1 (-16.3 – -13.9)	40	28.7 (2.6)	24.5 (2.5)	<0.0001
Mid	37	6804	5609	-17.6 (-18.5 – -16.7)	40	62.7 (2.7)	53.1 (3.3)	<0.0001
High	37	14,994	12,400	-17.3 (-17.9 – -16.7)	41	134.1 (21.6)	111.6 (20.8)	<0.0001

N: number of hospitals; n1: number of admissions immediately before COVID-19 pandemic; n2: number of admissions during COVID-19 pandemic; CI: confidence interval; SE: standard error.

Note: The n1 is based on 3 months before (December 2019–February 2020) COVID-19 pandemic.

^aThe monthly volume analysis is adjusted for peak COVID-19 volume for each country and the continent.

^bp: low vs. mid ≤ 0.0001 ; low vs. high ≤ 0.0001 ; mid vs. high ≤ 0.0001 .

^cp: low vs. mid = 0.001; low vs. high = 0.002; mid vs. high = 0.588.

Table 2. Mechanical thrombectomy overall and monthly volumes immediately before and during the COVID-19 pandemic

	Overall volume				Monthly volume ^a			
	N	n1	n2	Change % (95%CI)	N	Immediately before Adjusted mean (SE)	During COVID-19	p
Overall	176	5191	4533	-12.7 (-13.6 – -11.8)	173	10.9 (1.3)	9.8 (1.3)	<0.0001
Hospital COVID-19 volume ^b								
Low	44	952	869	-8.7 (-10.7 – -7.1)	44	11.2 (3.6)	10.5 (3.5)	0.044
Mid	45	1370	1232	-10.1 (-11.8 – -8.6)	45	11.7 (1.2)	10.8 (1.2)	0.004
High	45	1602	1273	-20.5 (-22.6 – -18.6)	46	7.8 (2.2)	5.7 (2.2)	<0.0001
Hospital MT volume ^c								
Low	59	459	412	-10.2 (-13.4 – -7.8)	60	2.6 (0.36)	2.3 (0.36)	0.082
Mid	55	1294	1092	-15.6 (-17.7 – -13.7)	55	8.1 (0.46)	7.0 (0.50)	0.0002
High	58	3432	3029	-11.7 (-12.9 – -10.7)	58	18.8 (1.8)	16.8 (1.7)	0.0002

N: number of hospitals; n1: number of procedures immediately before COVID-19 pandemic; n2: number of procedures during COVID-19 pandemic; CI: confidence interval; SE: standard error; MT: mechanical thrombectomy.

The n1 is based on three months before (December 2019–February 2020) COVID-19 pandemic.

^aThe monthly volume analysis is adjusted for peak COVID-19 volume for each country and the continent.

^bp: low vs. mid = 0.259; low vs. high ≤ 0.0001 ; mid vs. high ≤ 0.0001 .

^cp: low vs. mid = 0.004; low vs. high = 0.345; mid vs. high = 0.0003.

reported concomitant monthly data on stroke admission and MT volume. The adjusted mean (SE) monthly proportion of MT relative to stroke admissions remained stable across the pre-pandemic and pandemic periods (17.8 (2.2)% vs. 18.5 (2.2)%, respectively; $p = 0.150$). This proportional stability in MT performance was consistent across all COVID-19 and MT hospitalization volumes strata, Table S3.

Ischemic stroke/TIA and intracranial hemorrhage volumes

The ischemic stroke/TIA admission volumes declined from 19,882 to 16,884 patients across the three months preceding versus the pandemic months, corresponding to a 15.1% (95%CI, -15.6 to -14.6, $N=113$ sites) reduction with an adjusted mean (SE) number of ischemic stroke or TIA/month/center decreasing from 64.3 (6.8) to 55.6 (6.5) across the two epochs ($p < 0.0001$). Complete results are presented in Table S4.

The ICH admission volumes, submitted by 100 sites, decreased from 4002 to 3540 patients across the three months immediately before versus the pandemic months, representing an 11.5% (95%CI, -12.6 to -10.6) decline with the adjusted mean (SE) number of hospitalizations for ICH/month/center dropping from 13.4 (2.6) to 11.6 (2.6) across the two periods ($p < 0.0001$), Table S5.

Changes in stroke care metrics during the pandemic as a function of COVID-19 hospitalization volumes

Figures 1 and 2 provide the weekly volume of stroke admissions (ischemic and hemorrhagic), MT, and COVID-19 hospitalizations. COVID-19 hospital weekly volume data was available for 131 centers. There was an early peak of 1235 COVID-19 hospitalizations in February which predominantly originated from one hospital in Wuhan, China. Significant reductions in the mean monthly volumes were seen for all stroke care metrics across all tertiles of low, mid, and high COVID-19 hospitalization volumes. The exception was ICH volumes in high-volume COVID-19 centers which did not show a statistically significant difference (Tables 1, S4, and S5). High-volume COVID-19 centers (-20.5%; 95%CI, -22.6 to -18.6) had greater declines in MT volumes than mid- (-10.1%; 95%CI, -11.8 to -8.6; $p < 0.0001$) and low-volume (-8.7%; 95%CI, -10.7 to -7.1; $p < 0.0001$) COVID-19 centers, Table 2. Likewise, high-volume COVID-19 centers (-22.7%; 95%CI, -23.7 to -21.8) had greater reductions in stroke hospitalization volumes than mid- (-19.8%; 95%CI, -20.8 to -19.0; $p < 0.0001$) and low-volume

Figure 1. Weekly volume of stroke admissions (ischemic and hemorrhagic) and COVID-19 hospitalizations volumes.

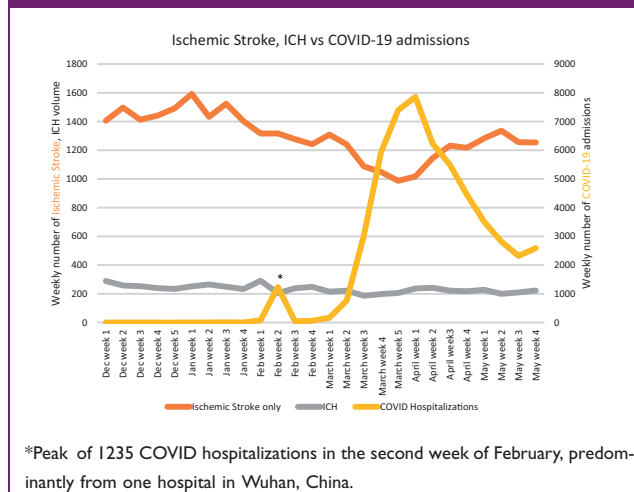
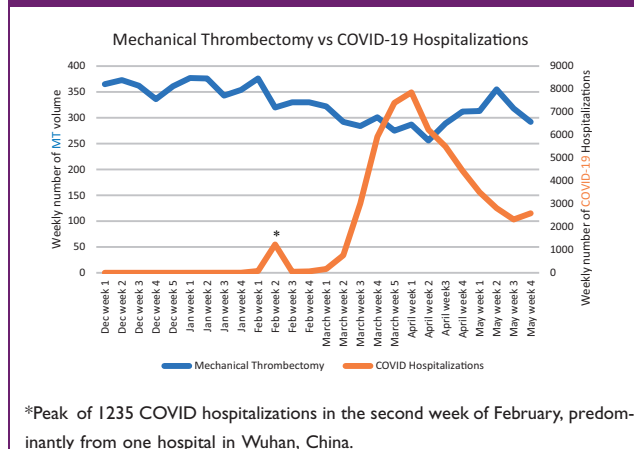


Figure 2. Weekly volume of mechanical thrombectomy and COVID-19 hospitalizations.



(-12.6%; 95%CI, -13.4 to -11.9; $p < 0.0001$) COVID-19 centers, Table 1.

Changes in stroke care metrics during the pandemic as a function of stroke center MT and admission volumes

Significant declines in the mean monthly volumes were observed for all stroke/MT metrics across low-, mid-, and high-volume stroke/MT centers except MT volumes in low-volume MT centers showed a trend in decline (Tables 1, 2, S4, and S5). Mid-volume stroke centers (-17.6%; 95% CI, -18.5 to -16.7) demonstrated greater decreases in stroke admission volumes

than low-volume (-15.1% ; 95%CI, -16.3 to -13.9 ; $p < 0.0001$) centers, Table 1.

Secondary objective

Table S6 depicts the volumes for overall stroke, ischemic stroke/TIA, ICH hospitalizations, and MT procedures during the first three months of the pandemic versus the corresponding period in the prior year. Compared to the prior year, there were significant declines in the monthly volumes for stroke and ischemic stroke/TIA admissions but not for ICH and MT.

Associations between the diagnoses of COVID-19 and stroke

There were 124 centers that reported patients with concomitant stroke (all subtypes) and SARS-CoV-2 infection. To reduce bias, 13 centers with no COVID-19 patients were excluded, leaving 111 eligible centers. A diagnosis of any stroke was present in 791 of 54,366 (1.45% ; 95% CI 1.35 – 1.55) COVID-19 hospitalizations. There was geographic variation with incidences ranging from 0.43% (95%CI 0.08 – 2.38) in Oceania to 11.9% in South America (95%CI 10.05 – 14.03), Table S7. Conversely, 784 of the 20,250 (3.9% , 95% CI 3.61 – 4.14) overall stroke admissions were diagnosed with COVID-19 with proportions varying from 0.14% (95%CI 0.03 – 0.78) in Oceania to 8.93% in South America (95%CI 7.54 – 10.55), Table S8.

Discussion

We noted a significant global decline in all measured stroke care metrics in the current study including the numbers of mechanical thrombectomy procedures (-12.7%), overall stroke admissions (-19.2%), ischemic stroke/TIA admissions (-15.1%), and intracranial hemorrhage hospitalization volumes (-11.5%) during the COVID-19 pandemic as compared to the immediately preceding three months, confirming our primary hypothesis. Volume reductions were also seen in relation to the equivalent period in the prior year for stroke admissions and ischemic/TIA admissions. The intensity of the decline was more pronounced when comparing the pandemic period with the immediate three months prior than with the same months in 2019 (MT: 12.7% vs. 6.0% ; stroke admissions: 19.2% vs. 12%). This followed our a priori expectations in face of the expansions in MT indications along with its progressive but gradual global implementation in developed and developing countries.¹⁷ Interestingly, despite the absolute decrease in MT volumes, the proportion of MT relative to stroke admissions remained stable during

the pandemic. While at first glance this might suggest that the intra-hospital workflow was maintained, it is possible that this was not the case since one would actually expect an increase in the MT ratio relative to stroke admissions as many studies have now demonstrated that there was a preferential decline in patients presenting with milder strokes during the pandemic.^{4,11,18–20} The decreases in the amount of stroke care were noted across centers with high, mid, and low COVID-19 hospitalization burden and also across high, mid, and low volume stroke and MT centers. As hypothesized, centers with higher COVID-19 inpatient volumes suffered more declines. Contrary to our expectations, the declines in stroke hospitalizations and MT volumes were more profound in mid-(and high-) volume than low-volume stroke centers. This might be related to the fact that larger centers were more likely to become the preferred destination for COVID-19 referrals leading to capacity issues. Finally, we confirmed a broad geographic variation in the patterns of stroke care decline.

Our results align with recent reports emphasizing the collateral effects of the COVID-19 pandemic on stroke systems of care from China,^{10,18} Spain,^{3,19} Italy,^{21,22} France,^{9,23} Germany,¹² Brazil,²⁰ Canada,²⁴ and United States,^{5,11,25,26} showing declines in the volumes for MT, IVT, and stroke hospitalizations over the pandemic (Table S9–11). Some of these studies also reported delays in hospital arrival times^{18,21,25} and treatment workflow.^{9,21} Our analysis adds to the growing literature regarding the collateral damage of COVID-19 on stroke care with the advantage of providing a broader global perspective. While the overall data clearly points to a significant reduction in the quantity of stroke care provided during the pandemic, it also depicts variations within and across the different regions reflecting the diversity in the epidemiology for COVID-19 as well as in the socio-cultural behaviors, healthcare logistics, and infrastructure encountered across the globe. Indeed, our study demonstrated important geographic variations in the proportional declines for both stroke hospitalization and MT volumes. Notably, our analysis may have underestimated the impact of geographic disparities in healthcare resources and related socio-economic factors as we only included thrombectomy capable centers which are known to have better infrastructure than the more commonly found primary stroke centers. Moreover, there was a higher geographic variation in the proportional decline for stroke hospitalization (Asia, -20.5% ; North America, -20.6% ; Europe, -11.2% ; South America, -15.9% , Oceania, -11.6% ; Africa, -48.1%) than mechanical thrombectomy (Asia, -9.8% ; North America, -14.5% ; Europe, -14.4% ;

South America, -12.4% , Oceania, -9.4% ; Africa, -21.2%) volumes. As seen in relation to the stability in the MT ratio relative to stroke admissions, this might have been related to the favored decline in milder strokes over the course of the pandemic.^{4,11,18–20} Given the growing evidence supporting the association between COVID-19 and thromboembolic events, it would be expected that the stroke incidence would rise at the precipice of the pandemic. Several factors may explain this paradoxical global decrease in stroke, MT, and ICH volumes observed in this study. As this decline in stroke volume was seen in centers with low or non-existent COVID-19 hospitalizations, hospital access due to the COVID-19 hospitalization burden was unlikely a major factor.¹² As elective surgeries were canceled with the pandemic, a decrease in perioperative stroke may have played a role. It is also conceivable that the environmental situation of a lockdown, with improved patient behaviors or medication compliance, may be protective in decreasing vascular events.²⁷ A reduction in exposure to other common viruses that may play a role in triggering vascular events may have also reduced stroke risk. However, it is unlikely that true incidence of stroke declined and more likely the behavioral and infrastructural changes related to the pandemic led to a reduction of admission of AIS patients, especially during the initial phases of public lockdown. Fear of contracting SARS-CoV-2 may have led many patients with milder stroke presentations to avoid seeking medical attention.^{4,11,18–20} Physical distancing measures may have prevented patients from the timely witnessing of a stroke.

Our subgroup of 111 centers including 54,366 COVID-19 hospitalizations is the largest sample reporting the concomitant diagnoses of stroke and SARS-CoV-2 infection to date. Our 1.45% stroke rate in COVID-19 hospitalizations is similar to the pooled incidence of $1.1\text{--}1.2\%$ (range, $0.9\text{--}2.7\%$) of hospitalized COVID-19 patients.^{28,29} Some variations in the proportions are expected given the different definitions (all strokes vs. ischemic only) and populations involved (all hospitalized vs. severely infected only) across studies. We also provide a new perspective on this relationship by reporting an incidence of 3.9% ($784/20,250$) for SARS-CoV-2 infection across all stroke admissions among centers with documented COVID-19 hospitalization.

Study strengths and limitations

The strength of our study was the large volume of patients ($n=64,416$) and a high number of centers ($n=187$) contributing data from a diverse population across six continents and 40 countries. Our study

contained centers with high and low COVID-19 hospitalization admissions, high and low stroke admission, and MT volumes, permitting the generation of multiple hypotheses and endpoints.

The limitations of this study were that the diagnosis of stroke/TIA/ICH, thrombectomy volume in some centers was obtained using hospital ICD administrative codes, and verification for accurate diagnosis was not universally undertaken. The centers contributing to these data have systems in place to track stroke admissions; thus, the relative changes in volume from this analysis are likely accurate. Details on patient-level data including demographics, stroke subtypes, and clinical outcomes were not collected as these were not the focus of the study. As with any other study, our data may underestimate true rates of concomitant SARS-CoV2 infection with a stroke diagnosis depending on the frequency of testing at each site and across the study period. The definition of the pandemic period was arbitrary since the outbreak started and peaked at different times at different locations. After adjustment for peak COVID-19 volume for each country and continent, the monthly volume declines were retained for all stroke metrics (stroke hospitalization, MT, ICH). As the penetration of MT remains limited in many countries,¹⁷ some geographic regions were not represented (i.e. central Africa). We did not collect data on the timing or intensity of social distancing policies including lockdown implementation across the different localities which likely played an important role in the reported stroke care decline. Finally, the sampling varied with the availability of complete data in each subset of the analysis.

Summary

There was a significant global decline in mechanical thrombectomy and stroke admissions over the three months studied during the pandemic. These decreases were seen regardless of COVID-19 admission burden, individual pre-pandemic stroke, and MT volumes. Thus, it is critical to expeditiously raise public awareness to prevent the additional healthcare consequences associated with the lack of stroke treatment. These findings can inform regional stroke networks preparedness²⁹ in the face of a future pandemic or anticipated surge of COVID-19 cases in order to ensure that the access and quality of stroke care remains preserved despite the crises imposed by the continuous spread of the virus.

Acknowledgements

Patrick Nicholson, MD, Jasmine Johann, MSN, FNP-BC, Judith Clark, RN, Matt Metzinger, MBA, CPHQ, Jefferson, Kamini Patel, RN, MBA, Janis Ginnane, RN.

Disclosures

Dr Nguyen: Medtronic.

Dr Nogueira: Stryker; Cerenovus/Neuravi; Ceretrieve.

Dr Walker: Medtronic, Cerenovus.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship, and/or publication of this article.

ORCID iDs

Y Mansour  <https://orcid.org/0000-0001-8814-6431>

Zhongming Qiu  <https://orcid.org/0000-0002-1622-9526>

James E Siegler  <https://orcid.org/0000-0003-0287-3967>

Laura Mechtouff  <https://orcid.org/0000-0001-9165-5763>

Omer Eker  <https://orcid.org/0000-0002-5696-5368>

Raoul Pop  <https://orcid.org/0000-0003-4417-1496>

Juan F Arenillas  <https://orcid.org/0000-0001-7464-6101>

Mahmoud Mohammaden  <https://orcid.org/0000-0002-7393-9989>

Simon Nagel  <https://orcid.org/0000-0003-2471-6647>

Mudassir Farooqui  <https://orcid.org/0000-0003-3697-5697>

Ameer E Hassan  <https://orcid.org/0000-0002-7148-7616>

Allan Taylor  <https://orcid.org/0000-0002-2692-2068>

Bertrand Lapergue  <https://orcid.org/0000-0002-8993-2175>

Bruce CV Campbell  <https://orcid.org/0000-0003-3632-9433>

Noel Van Horn  <https://orcid.org/0000-0001-5764-1982>

Ryoo Yamamoto  <https://orcid.org/0000-0001-8585-9831>

Takehiro Yamada  <https://orcid.org/0000-0001-5196-1934>

Yukako Yazawa  <https://orcid.org/0000-0003-3891-0221>

Jane Morris  <https://orcid.org/0000-0001-5256-8165>

Michael D Hill  <https://orcid.org/0000-0002-6269-1543>

Thanh Nguyen  <https://orcid.org/0000-0002-2810-1685>

Authors

Raul G. Nogueira^{1,*}, Mohamad Abdalkader², Muhammed M. Qureshi³, Michael R. Frankel⁴, Ossama Yassin Mansour^{5,**}, Hiroshi Yamagami^{6,#}, Zhongming Qiu⁷, Mehdi Farhoudi⁸, James E. Siegler⁹, Shadi Yaghi¹⁰, Eytan Raz¹¹, Nobuyuki Sakai^{12,#}, Nobuyuki Ohara^{13,#}, Michel Piotin¹⁴, Laura Mechtouff¹⁵, Omer Eker¹⁶, Vanessa Chalumeau¹⁷, Timothy J. Kleinig¹⁸, Raoul Pop¹⁹, Jianmin Liu²⁰, Hugh S. Winters²¹, Xianjin Shang²², Alejandro Rodriguez Vasquez²³, Jordi Blasco²⁴, Juan F. Arenillas²⁵, Mario Martinez-Galdamez²⁶, Alex Brehm²⁷, Marios Nikos Psychogios²⁷, Pedro Lylyk²⁸, Diogo C. Haussen²⁹, Alhamza R. Al-Bayati²⁹, Mahmoud H. Mohammaden²⁹, Luísa Fonseca³⁰, M. Luís Silva³¹, Francisco Montalverne³², Leonardo Renieri³³, Salvatore Mangiafico³³, Urs Fischer³⁴, Jan Gralla³⁵, Donald Frei³⁶, Chandril Chugh³⁷, Brijesh P. Mehta³⁸, Simon Nagel³⁹, Markus Mohlenbruch⁴⁰,

Santiago Ortega-Gutierrez⁴¹, Mudassir Farooqui⁴¹, Ameer E. Hassan⁴², Allan Taylor⁴³, Bertrand Lapergue⁴⁴, Arturo Consoli⁴⁵, Bruce CV Campbell⁴⁶, Malveeka Sharma⁴⁷, Melanie Walker⁴⁸, Noel Van Horn⁴⁹, Jens Fiehler⁴⁹, Huy Thang Nguyen⁵⁰, Quoc T. Nguyen⁵⁰, Daisuke Watanabe⁵¹, Hao Zhang⁵², Huynh V. Le⁵³, Viet Q. Nguyen⁵³, Ruchir Shah⁵⁴, Thomas Devlin⁵⁴, Priyank Khandelwal⁵⁵, Italo Linfante⁵⁶, Wazim Izzath⁵⁷, Pablo M. Lavados⁵⁸, Veronica V. Olavarria⁵⁸, Gisele Sampaio Silva⁵⁹, Anna Verena de Carvalho Sousa⁶⁰, Jawad Kirmani⁶¹, Martin Bendszus⁶², Tatsuo Amano⁶³, Ryoo Yamamoto⁶⁴, Ryosuke Doijiri⁶⁵, Naoki Tokuda⁶⁶, Takehiro Yamada⁶⁷, Tadashi Terasaki⁶⁸, Yukako Yazawa⁶⁹, Jane G. Morris⁷⁰, Emma Griffin⁷¹, John Thornton⁷¹, Pascale Lavoie⁷², Charles Matouk⁷³, Michael D. Hill⁷⁴, Andrew M. Demchuk⁷⁴, Monika Killer-Oberpfalzer⁷⁵, Fadi Nahab⁷⁶, Dorothea Altschul⁷⁷, Anna Ramos-Pachón⁷⁸, Natalia Pérez de la Ossa⁷⁸, Raghd Kikano⁷⁹, William Boisseau⁸⁰, Gregory Walker⁸¹, Steve M. Cordina⁸², Ajit Puri⁸³, Anna Luisa Kuhn⁸³, Dheeraj Gandhi⁸⁴, Pankajavalli Ramakrishnan⁸⁵, Roberta Novakovic-White⁸⁶, Alex Chebl⁸⁷, Odysseas Kargiotis⁸⁸, Alexandra Czap⁸⁹, Alicia Zha⁸⁹, Hesham E. Masoud⁹⁰, Carlos Lopez⁹⁰, David Ozretic⁹¹, Fawaz Al-Mufti⁹², Wenjie Zie⁹³, Zhenhui Duan⁹⁴, Zhengzhou Yuan⁹⁵, Wenguo Huang⁹⁶, Yonggang Hao⁹⁷, Jun Luo⁹⁸, Vladimir Kalousek⁹⁹, Romain Bourcier¹⁰⁰, Romain Guile¹⁰⁰, Steven Hetts¹⁰¹, Hosam M. Al-Jehani¹⁰², Adel AlHazzani¹⁰³, Elyar Sadeghi-Hokmabadi¹⁰⁴, Mohamed Teleb¹⁰⁵, Jeremy Payne¹⁰⁵, Jin Soo Lee¹⁰⁶, Ji Man Hong¹⁰⁶, Sung-Il Sohn¹⁰⁷, Yang-ha Hwang¹⁰⁸, Dong Hoon Shin¹⁰⁹, Hong Gee Roh¹¹⁰, Randy Edgell¹¹¹, Rakesh Khatri¹¹², Ainsley Smith¹¹³, Amer Malik¹¹⁴, David Liebeskind¹¹⁵, Nabeel Herial¹¹⁶, Pascal Jabbour¹¹⁶, Pedro Magalhães¹¹⁷, Atila Ozcan Ozdemir¹¹⁸, Ozlem Aykac¹¹⁸, Takeshi Uwatoko¹¹⁹, Tomohisa Dembo¹²⁰, Hisao Shimizu¹²¹, Yuri Sugiura¹²², Fumio Miyashita¹²³, Hiroki Fukuda¹²⁴, Kosuke Miyake¹²⁵, Junsuke Shimbo¹²⁶, Yusuke Sugimura¹²⁷, Andre Beer-Furlan¹²⁸, Krishna Joshi¹²⁸, Luciana Catanese¹²⁹, Daniel Giansante Abud¹³⁰, Octavio Pontes Neto¹³¹, Masoud Mehrpour¹³², Amal Al Hashmi¹³³, Mahar Saqqur¹³⁴, Abdulrahman Mostafa¹³⁵, Johanna T. Fifi¹³⁶, Syed Hussain¹³⁷, Seby John¹³⁷, Rishi Gupta¹³⁸, Rotem Sivan-Hoffmann¹³⁹, Anna Reznik¹³⁹, Achmad Fidaus Sani¹⁴⁰, Serdar Geyik¹⁴¹, Eşref Akıl¹⁴¹, Anchalee Churojana¹⁴², Abdoreza Ghoreishi¹⁴³, Mohammad Saadatnia¹⁴⁴, Ehsan Sharifipour¹⁴⁵, Alice Ma¹⁴⁶, Ken Faulder¹⁴⁶, Teddy Wu¹⁴⁷, Lester Leung¹⁴⁸, Adel Malek¹⁴⁹, Barbara Voetsch¹⁵⁰, Ajay Wakhloo¹⁵¹, Rodrigo Rivera¹⁵², Danny Moises Barrientos Iman¹⁵³, Aleksandra Pikula¹⁵⁴, Vasileios-Arsenios Lioutas¹⁵⁵, Gotz Thomalla¹⁵⁶, Lee Birnbaum¹⁵⁷, Paolo Machi¹⁵⁸, Gianmarco Bernava¹⁵⁸, Mollie McDermott¹⁵⁹, Dawn Kleindorfer¹⁵⁹, Ken Wong¹⁶⁰, Mary S. Patterson¹⁶¹, Jose Antonio Fiorot, Jr¹⁶², Vikram Huded¹⁶³, William Mack¹⁶⁴, Matthew Tenser¹⁶⁴, Clifford Eskey¹⁶⁵, Sumeet Multani¹⁶⁶, Michael Kelly¹⁶⁷, Vallabh Janardhan¹⁶⁸, Oriana Cornett¹⁶⁹, Varsha Singh¹⁶⁹, Yuichi Murayama¹⁷⁰, Maxim Mokin¹⁷¹, Pengfei Yang¹⁷², Xiaoxi Zhang¹⁷², Congguo Yin¹⁷³, Hongxing Han¹⁷⁴, Ya Peng¹⁷⁵, Wenhao Chen¹⁷⁶, Roberto Crosa¹⁷⁷, Michel Eli Frudit¹⁷⁸,

Jeyaraj D.Pandian¹⁷⁹, Anirudh Kulkarni¹⁷⁹, Yoshiki Yagita¹⁸⁰, Yohei Takenobu¹⁸¹, Yuji Matsumaru¹⁸², Satoshi Yamada¹⁸³, Ryuhei Kono¹⁸⁴, Takuya Kanamaru¹⁸⁵, Hidekazu Yamazaki¹⁸⁶, Manabu Sakaguchi¹⁸⁷, Kenichi Todo¹⁸⁸, Nobuaki Yamamoto¹⁸⁹, Kazutaka Sonoda¹⁹⁰, Tomoko Yoshida¹⁹¹, Hiroyuki Hashimoto¹⁹², Ichiro Nakahara¹⁹³, Elena Cora, MD¹⁹⁴, David Volders¹⁹⁴, Celina Ducroux¹⁹⁵, Ashkan Shoamanesh¹⁹⁶, Johanna Ospel¹⁹⁷, Artem Kaliev¹⁹⁸, Saima Ahmed¹⁹⁹, Umair Rashid¹⁹⁹, Leticia C. Rebello²⁰⁰, Vitor Mendes Pereira²⁰¹, Robert Fahed²⁰², Michael Chen²⁰³, Sunil A Sheth²⁰⁴, Lina Palaiodimou²⁰⁵, Georgios Tsigoulis²⁰⁵, Ronil Chandra²⁰⁶, Feliks Koyfman²⁰⁷, Thomas Leung²⁰⁸, Houman Khosravani²⁰⁹, Sushrut Dharmadhikari²¹⁰, Giovanni Frisullo²¹¹, Paolo Calabresi²¹¹, Alexander Tsiskaridze²¹², Nino Lobjanidze²¹², Mikayel Grigoryan²¹³, Anna Czlonkowska²¹⁴, Diana Aguiar de Sousa²¹⁵, Jelle Demeestere²¹⁶, Conrad Liang²¹⁷, Navdeep Sangha²¹⁸, Helmi L. Lutsep²¹⁹, Óscar Ayo-Martin²²⁰, Antonio Cruz-Culebras²²¹, Anh D. Tran²²², Chang Y. Young²²³, Charlotte Cordonnier²²⁴, Francois Caparros²²⁴, Maria Alonso De Lecinana²²⁵, Blanca Fuentes²²⁵, Dileep Yavagal²²⁶, Tudor Jovin²²⁷, Laurent Spelle²²⁸, Jacques Moret²²⁸, Pooja Khatri²²⁹, Osama Zaidat²³⁰, Jean Raymond²³¹, Sheila Martins²³², Thanh Nguyen^{233*}. On behalf of the SVIN COVID-19 Global Registry, the Middle East North Africa Stroke and Interventional Neurotherapies Organization (MENA-SINO)** and Japanese Vascular and Interventional Neurology Society (JVIN)#

*Drs. Nogueira and Nguyen contributed equally to this article.

¹Neurology, Grady Memorial Hospital, Emory University, Atlanta, Georgia, USA

²Radiology, Boston Medical Center, Boston University School of Medicine, Boston, USA

³Radiology, Radiation Oncology, Boston Medical Center, Boston University School of Medicine, Boston, USA

⁴Neurology, Grady Memorial Hospital, Emory University, Atlanta, Georgia, USA

⁵Neurology Department, Stroke and Neurointervention Division, Alexandria University Hospital, Alexandria University, Egypt

⁶Stroke Neurology, National Hospital Organization, Osaka National Hospital, Japan

⁷Neurology, Xinqiao Hospital of the Army Medical University, Chongqing, China

⁸Tabriz University, Iran

⁹Neurology, Cooper Neurological Institute, Cooper University Hospital, Camden, New Jersey, USA

¹⁰Neurology, Radiology, New York University School of Medicine, New York, USA

¹¹Radiology, Neurology, New York University School of Medicine, New York, USA

¹²Neurosurgery, Kobe City Medical Center General Hospital, Kobe, Japan

¹³Neurology, Kobe City Medical Center General Hospital, Kobe, Japan

¹⁴Fondation Ophtalmologique Adolphe de Rothschild, France

¹⁵Neurologie, Hospices Civils de Lyon, France

¹⁶Neuroradiologie, Hospices Civils de Lyon, France

¹⁷Hôpital Bicêtre, Paris, France

¹⁸Royal Adelaide Hospital, Australia

¹⁹Hôpitaux Universitaires de Strasbourg, France

²⁰Changhai Hospital, Shanghai, China

²¹Royal Prince Alfred Hospital, Sydney, Australia

²²Yijishan Hospital of Wannan Medical College, China

²³Neurology, Hospital Clinic de Barcelona, Spain

²⁴Interventional Neuroradiology, Hospital Clinic de Barcelona, Spain

²⁵Neurology, Hospital Clínico Universitario, Valladolid, Spain

²⁶Interventional Neuroradiology, Hospital Clínico Universitario, Valladolid, Spain

²⁷University Hospital Basel, Switzerland

²⁸Clínica Sagrada Familia, Buenos Aires, Argentina

²⁹Neurology, Grady Memorial Hospital, Emory University, Atlanta, Georgia, USA

³⁰Stroke, Centro Hospitalar Universitário de São João, Portugal

³¹Neuroradiology, Centro Hospitalar Universitário de São João, Portugal

³²Hospital Geral de Fortaleza, Brazil

³³Careggi University Hospital, Florence, Italy

³⁴Neurology, University Hospital Bern, Switzerland

³⁵Interventional Neuroradiology, University Hospital Bern, Switzerland

³⁶Swedish Medical Center, USA

³⁷MAX Superspecialty Hospital, India

³⁸Memorial Neuroscience Institute, Florida

³⁹Neurology, University Hospital Heidelberg, Germany

⁴⁰Neuroradiology, University Hospital Heidelberg, Germany

⁴¹Neurology, University of Iowa, USA

⁴²Neurosciences, Valley Baptist Medical Center, Harlingen, Texas, USA

⁴³Neurosurgery, University of Cape Town, South Africa

⁴⁴Neurology, Hôpital Foch, France

⁴⁵Interventional Neuroradiology, Hôpital Foch, France

⁴⁶Royal Melbourne Hospital, Melbourne, Australia

⁴⁷Neurology, University of Washington, Seattle, USA

⁴⁸Neurosurgery, University of Washington, Seattle, USA

⁴⁹Interventional Neuroradiology, Universitätsklinikum Hamburg-Eppendorf, Germany

⁵⁰People's 115 Hospital, Vietnam

⁵¹IMS Tokyo-Katsushika General Hospital, Japan

⁵²Affiliated Hangzhou First People's Hospital, China

⁵³Hue Central Hospital, Vietnam

⁵⁴Erlanger Medical Center, USA

⁵⁵Rutgers University, USA

⁵⁶Miami Cardiac and Vascular Institute, USA

⁵⁷Nottingham University Hospitals, United Kingdom

⁵⁸Clínica Alemana, Universidad del Desarrollo, Chile

⁵⁹Universidade Federal de Sao Paulo Hospital Israelita Albert Einstein, Brazil

⁶⁰Hospital Israelita Albert Einstein, Brazil

⁶¹Hackensack Meridian Health, New Jersey, USA

⁶²Neuroradiology, University Hospital Heidelberg, Germany

⁶³Kyorin University, Japan 64 Yokohama Brain and Spine Center, Japan

- ⁶⁵Iwate Prefectural Central Hospital, Japan
- ⁶⁶Japanese Red Cross Kyoto Daiichi Hospital, Japan
- ⁶⁷Kyoto Second Red Cross Hospital, Japan
- ⁶⁸Japanese Red Cross Kumamoto Hospital, Japan
- ⁶⁹Kohnan Hospital, Japan
- ⁷⁰Neurology, Maine Medical Center, USA
- ⁷¹Beaumont Hospital, Dublin, Ireland
- ⁷²Hopital Enfant Jesus, Quebec City, Canada
- ⁷³Yale New Haven Hospital, USA
- ⁷⁴Neurology, University of Calgary, Canada
- ⁷⁵University Hospital Salzburg, Austria
- ⁷⁶Emory University School of Medicine, USA
- ⁷⁷Valley Hospital, New Jersey, USA
- ⁷⁸University Hospital Germans Trias i Pujol, Barcelona, Spain
- ⁷⁹Lau Medical Center, Beirut, Lebanon
- ⁸⁰CHU Montreal, Canada
- ⁸¹University of Ottawa, Canada
- ⁸²University of South Alabama, USA
- ⁸³University of Massachusetts Medical Center, USA
- ⁸⁴University of Maryland, USA
- ⁸⁵Riverside Regional Medical Center, Virginia, USA
- ⁸⁶UT Southwestern, Dallas, Texas, USA
- ⁸⁷Henry Ford Health System, Detroit, USA
- ⁸⁸Metropolitan Hospital, Piraeus, Greece
- ⁸⁹UTHealth McGovern Medical School, Houston, USA
- ⁹⁰SUNY Upstate Medical University Hospital, USA
- ⁹¹University Hospital Centre Zagreb, Croatia
- ⁹²Westchester Medical Center, USA
- ⁹³Xinqiao Hospital of the Army Medical University, China
- ⁹⁴Wuhan No.1 Hospital, China
- ⁹⁵Affiliated Hospital of Southwest Medical University, China
- ⁹⁶Maoming Traditional Chinese Medicine Hospital, China
- ⁹⁷Shaw Shaw Hospital, China
- ⁹⁸Mianyang 404 Hospital, China
- ⁹⁹University Clinical Hospital Center Sestre Milosrdnice, Croatia
- ¹⁰⁰CHU Nantes, France
- ¹⁰¹University of California San Francisco, USA
- ¹⁰²King Fahad Hospital of the University, Saudi Arabia
- ¹⁰³King Saud University, Saudi Arabia
- ¹⁰⁴Tabriz University, Iran
- ¹⁰⁵Banner Desert Medical Center, USA
- ¹⁰⁶Ajou University Hospital, Korea
- ¹⁰⁷Kyemyung University, Korea
- ¹⁰⁸Kyungpook National University Hospital, Korea
- ¹⁰⁹Gachon University Gil Hospital, Korea
- ¹¹⁰Konkuk University Hospital, Korea
- ¹¹¹St. Louis University, USA
- ¹¹²Texas Tech University, USA
- ¹¹³Cooper University Hospital, USA
- ¹¹⁴University of Miami, USA
- ¹¹⁵UCLA, Los Angeles, USA
- ¹¹⁶Thomas Jefferson University Hospital, USA
- ¹¹⁷Hospital Sao Jose, Brazil
- ¹¹⁸Eskisehir Osmangazi University, Turkey
- ¹¹⁹Saga-ken Medical Centre Koseikan, Japan
- ¹²⁰Saitama Medical Center, Japan
- ¹²¹Nara City Hospital, Japan
- ¹²²Toyonaka Municipal Hospital, Japan
- ¹²³Kagoshima City Hospital, Japan
- ¹²⁴Japanese Red Cross Matsue Hospital, Japan
- ¹²⁵Shiroyama Hospital, Japan
- ¹²⁶Niigata City General Hospital, Japan
- ¹²⁷Sugimura Hospital, Kumamoto, Japan
- ¹²⁸Rush University Medical Center, USA
- ¹²⁹Neurology, McMaster University, Canada
- ¹³⁰Interventional Neuroradiology, Ribeirão Preto Medical School, Brazil
- ¹³¹Neurosciences, Ribeirão Preto Medical School, Brazil
- ¹³²Shahid Beheshti University, Iran
- ¹³³Khoulia Hospital, Ministry of Health, Oman
- ¹³⁴Hamad Medical Corporation, Qatar
- ¹³⁵Alexandria University Hospital, Egypt Hamad Medical Corporation, Qatar
- ¹³⁶Mount Sinai Health System, New York, USA
- ¹³⁷Cleveland Clinic Abu Dhabi, UAE
- ¹³⁸WellStar Health, Marietta, Georgia, USA
- ¹³⁹Rambam Health Care, Israel
- ¹⁴⁰General Hospital Dr. Soetomo, Indonesia
- ¹⁴¹Istanbul Aydın University, Turkey
- ¹⁴²Siriraj Hospital, Thailand
- ¹⁴³Zanjan University, Iran
- ¹⁴⁴Isfahan University, Iran
- ¹⁴⁵Qom University, Iran
- ¹⁴⁶Royal North Shore Hospital, Australia
- ¹⁴⁷Christchurch Hospital, Christchurch, New Zealand
- ¹⁴⁸Neurology, Tufts Medical Center, USA
- ¹⁴⁹Neurosurgery, Tufts Medical Center, USA
- ¹⁵⁰Neurology, Beth Israel Lahey Health, USA
- ¹⁵¹Interventional Neuroradiology, Beth Israel Lahey Health, USA
- ¹⁵²Neuroradiology, Instituto de Neurocirugia Dr. Asengo, Chile
- ¹⁵³National Institute of Neurological Sciences of Lima, Peru
- ¹⁵⁴University of Toronto, Canada
- ¹⁵⁵Neurology, Beth Israel Lahey Health, USA
- ¹⁵⁶Neurology, Universitätsklinikum Hamburg-Eppendorf, Germany
- ¹⁵⁷University of Texas San Antonio, USA
- ¹⁵⁸University Hospitals of Geneva, Switzerland
- ¹⁵⁹University of Michigan, USA
- ¹⁶⁰Royal London Hospital, United Kingdom
- ¹⁶¹Bon Secours Mercy Health, USA
- ¹⁶²Hospital-Estadual Central, Brazil
- ¹⁶³NH Mazumdar Shaw Medical Center, India
- ¹⁶⁴University of Southern California, USA
- ¹⁶⁵Dartmouth Hitchcock Medical Center, Lebanon, New Hampshire, USA
- ¹⁶⁶Neurology, Bayhealth Medical Center, Delaware, USA
- ¹⁶⁷Neurosurgery, University of Saskatchewan, Canada
- ¹⁶⁸Medical City Plano Texas, USA
- ¹⁶⁹St. Joseph's University Medical Center, USA
- ¹⁷⁰Jikei University School of Medicine, Japan
- ¹⁷¹University of South Florida, USA
- ¹⁷²Changhai Hospital, Shanghai, China

¹⁷³Affiliated Hangzhou First People's Hospital, China
¹⁷⁴Linyi City People Hospital, China
¹⁷⁵First People's Hospital, China
¹⁷⁶Zhangzhou Municipal Hospital, China
¹⁷⁷Centro Endovascular Neurológico Médica, Uruguay
¹⁷⁸Universidade Federal de Sao Paulo, Brazil
¹⁷⁹Christian Medical College, India
¹⁸⁰Kawasaki Medical School, Japan
¹⁸¹Osaka Red Cross Hospital, Japan
¹⁸²University of Tsukuba, Japan
¹⁸³Saiseikai Central Hospital, Japan
¹⁸⁴Kinikyochuo Hospital, Japan
¹⁸⁵NTT Medical Center, Japan
¹⁸⁶Yokohama Shintoshu Neurosurgical Hospital, Japan
¹⁸⁷Osaka General Medical Center, Japan
¹⁸⁸Osaka University Graduate School of Medicine, Japan
¹⁸⁹Tokushima University Graduate School of Biomedical Sciences, Japan
¹⁹⁰Saiseikai Fukuoka General Hospital, Japan
¹⁹¹Tane General Hospital, Japan
¹⁹²Osaka Rosai Hospital, Japan
¹⁹³Fujita Health University School of Medicine, Japan
¹⁹⁴Dalhousie University, Nova Scotia, Canada
¹⁹⁵CHU Montreal, Montreal, Canada
¹⁹⁶McMaster University, Canada
¹⁹⁷University of Calgary, Canada
¹⁹⁸Radiology, Boston Medical Center, USA
¹⁹⁹Lahore General Hospital, Pakistan
²⁰⁰Hospital Brasilia, Brazil
²⁰¹University of Toronto, Canada
²⁰²University of Ottawa, Canada
²⁰³Rush University Medical Center, USA
²⁰⁴UTHealth McGovern Medical School, Houston, USA
²⁰⁵National & Kapodistrian University of Athens, Greece
²⁰⁶Monash Medical Center, Australia
²⁰⁷New York-Presbyterian Queens, USA
²⁰⁸Prince of Wales Hospital, Hong Kong
²⁰⁹Sunnybrook Health Sciences Centre, Canada
²¹⁰Baptist Health, Arkansas, USA
²¹¹Fondazione Policlinico Universitario A. Gemelli, Italy
²¹²Ivane Javakhishvili Tbilisi State University, Georgia
²¹³Adventist Health Glendale, USA
²¹⁴Institute Psychiatry and Neurology, Poland
²¹⁵Hospital de Santa Maria, Portugal
²¹⁶Leuven University Hospital, Belgium
²¹⁷Neurointerventional Radiology, Kaiser Permanente, California, USA
²¹⁸Neurology, Kaiser Permanente, California, USA
²¹⁹Oregon University, USA
²²⁰Complejo Hospitalario Universitario de Albacete, Spain
²²¹Hospital Universitario Ramon y Cajal, Unidad de Ictus, Spain
²²²Hue Central Hospital, Vietnam
²²³Asan Medical Center, Korea
²²⁴CHU de Lille, France
²²⁵La Paz University Hospital, Madrid, Spain
²²⁶University of Miami, USA
²²⁷Cooper University Hospital, USA
²²⁸Hôpital Bicêtre, Paris, France
²²⁹University of Cincinnati, USA

²³⁰Bon Secours Mercy Health, Toledo, Ohio, USA
²³¹CHU Montreal, Canada
²³²Hospital de Clínicas de Porto Alegre, Brazil
²³³Radiology, Neurology, Boston Medical Center, USA

Supplemental material

Supplemental material for this article is available online.

References

1. Zubair AS McAlpine LS Gardin T Farhadian S Kuruvilla DE and Spudich S. Neuropathogenesis and neurologic manifestations of the coronaviruses in the age of coronavirus disease 2019: a review. *JAMA Neurol* 2020; 77: 1018–1027.
2. Oxley TJ Mocco J Majidi S, et al. Large-vessel stroke as a presenting feature of Covid-19 in the young. *N Engl J Med* 2020; 382: e60.
3. Rudilosso S Laredo C Vera V, et al. Acute stroke care is at risk in the era of COVID-19: experience at a comprehensive stroke center in Barcelona. *Stroke* 2020; 51: 1991–1995.
4. Yaghi S Ishida K Torres J, et al. SARS-CoV-2 and stroke in a New York Healthcare System. *Stroke* 2020; 51: 2002–2011.
5. Onteddu SR Nalleballe K Sharma R and Brown AT. Underutilization of health care for strokes during the COVID-19 outbreak. *Int J Stroke* 2020; 15: NP9–NP10.
6. Varga Z Flammer AJ Steiger P, et al. Endothelial cell infection and endotheliitis in COVID-19. *Lancet* 2020; 395: 1417–1418.
7. Connors JM and Levy JH. COVID-19 and its implications for thrombosis and anticoagulation. *Blood* 2020; 135: 2033–2040.
8. Kansagra AP Goyal MS Hamilton S and Albers GW. Collateral effect of Covid-19 on stroke evaluation in the United States. *N Engl J Med* 2020; 383: 400–401.
9. Kerleroux B Fabacher T Bricout N, et al. Mechanical thrombectomy for acute ischemic stroke amid the COVID-19 outbreak: decreased activity, and increased care delays. *Stroke* 2020; 51: 2012–2017.
10. Zhao J Li H Kung D Fisher M Shen Y and Liu R. Impact of the COVID-19 epidemic on stroke care and potential solutions. *Stroke* 2020; 51: 1996–2001.
11. Siegler JE Heslin ME Thau L Smith A and Jovin TG. Falling stroke rates during COVID-19 pandemic at a comprehensive stroke center. *J Stroke Cerebrovasc Dis* 2020; 29: 104953.
12. Hoyer C Ebert A Huttner HB, et al. Acute stroke in times of the COVID-19 pandemic: a multicenter study. *Stroke* 2020; 51: 2224–2227.
13. Román LS Menon BK Blasco J, et al. Imaging features and safety and efficacy of endovascular stroke treatment: a meta-analysis of individual patient-level data. *Lancet Neurol* 2018; 17: 895–904.
14. Nogueira RG Jadhav AP Haussen DC, et al. Thrombectomy 6 to 24 hours after stroke with a mismatch between deficit and infarct. *N Engl J Med* 2018; 378: 11–21.

15. Albers GW Marks MP Kemp S, et al. Thrombectomy for stroke at 6 to 16 hours with selection by perfusion imaging. *N Engl J Med* 2018; 378: 708–718.
16. Liao JN Chao TF Liu CJ, et al. Seasonal variation in the risk of ischemic stroke in patients with atrial fibrillation: a nationwide cohort study. *Heart Rhythm* 2018; 15: 1611–1616.
17. Martins SO Mont'Alverne F Rebello LC, et al. Thrombectomy for stroke in the public health care system of Brazil. *N Engl J Med* 2020; 382: 2316–2326.
18. Teo KC Leung WCY Wong YK, et al. Delays in stroke onset to hospital arrival time during COVID-19. *Stroke* 2020; 51: 2228–2231.
19. Montaner J Barragán-Prieto A Pérez-Sánchez S, et al. Break in the stroke chain of survival due to COVID-19. *Stroke* 2020; 51: 2307–2314.
20. Diegoli H Magalhães PSC Martins SCO, et al. Decrease in hospital admissions for transient ischemic attack, mild, and moderate stroke during the COVID-19 era. *Stroke* 2020; 51: 2315–2321.
21. Baracchini C Pieroni A Viaro F, et al. Acute stroke management pathway during coronavirus-19 pandemic. *Neurol Sci* 2020; 41: 1003–1005.
22. Morelli N Rota E Terracciano C, et al. The baffling case of ischemic stroke disappearance from the Casualty Department in the COVID-19 era. *Eur Neurol* 2020; 83: 213–215.
23. Pop R Quenardelle V Hasiu A, et al. Impact of the COVID-19 outbreak on acute stroke pathways - insights from the Alsace region in France. *Eur J Neurol* 2020; 27: 1783–1787.
24. Bullrich MB Fridman S Mandzia JL, et al. COVID-19: stroke admissions, emergency department visits, and prevention clinic referrals. *Can J Neurol Sci* 2020; 47: 693–696.
25. Schirmer CM Ringer AJ Arthur AS, et al; Endovascular Research Group (ENRG). Delayed presentation of acute ischemic strokes during the COVID-19 crisis. *J Neurointerv Surg* 2020; 12: 639–642.
26. Uchino K Kolikonda MK Brown D, et al. Decline in stroke presentations during COVID-19 surge. *Stroke* 2020; 51: 2544–2547.
27. American Heart Association's Mission: Lifeline and Get With The Guidelines Coronary Artery Disease Advisory Work Group and the Council on Clinical Cardiology's Committees on Acute Cardiac Care and General Cardiology and Interventional Cardiovascular Care*. Temporary Emergency Guidance to STEMI Systems of Care During the COVID-19 Pandemic: AHA's Mission: Lifeline. *Circulation* 2020; 142: 199–202.
28. Tan YK Goh C Leow AST, et al. COVID-19 and ischemic stroke: a systematic review and meta-summary of the literature. *J Thromb Thrombol* 2020; 50: 587–595.
29. Nguyen TN Abdalkader M Jovin TG, et al. Mechanical thrombectomy in the era of the COVID-19 pandemic: emergency preparedness for neuroscience teams: a guidance statement from the Society of Vascular and Interventional Neurology. *Stroke* 2020; 51: 1896–1901.