



HAL
open science

Decline in subarachnoid haemorrhage volumes associated with the first wave of the COVID-19 pandemic

T. N. Nguyen, D. C. Haussen, M. M. Qureshi, H. Yamagami, T. Fujinaka, O. Y. Mansour, M. Abdalkader, M. Frankel, Z. Qiu, A. Taylor, et al.

► To cite this version:

T. N. Nguyen, D. C. Haussen, M. M. Qureshi, H. Yamagami, T. Fujinaka, et al.. Decline in subarachnoid haemorrhage volumes associated with the first wave of the COVID-19 pandemic. *Stroke and Vascular Neurology*, 2021, pp.svn-2020-000695. 10.1136/svn-2020-000695 . inserm-03337432

HAL Id: inserm-03337432

<https://inserm.hal.science/inserm-03337432>

Submitted on 8 Sep 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Decline in subarachnoid haemorrhage volumes associated with the first wave of the COVID-19 pandemic

To cite: Nguyen TN, Haussen DC, Qureshi MM, *et al.* Decline in subarachnoid haemorrhage volumes associated with the first wave of the COVID-19 pandemic. *Stroke & Vascular Neurology* 2021;0. doi:10.1136/svn-2020-000695

► Additional material is published online only. To view, please visit the journal online (<http://dx.doi.org/10.1136/svn-2020-000695>).

TNN and RGN contributed equally.

Received 19 October 2020
Revised 15 December 2020
Accepted 15 January 2021



© Author(s) (or their employer(s)) 2021. Re-use permitted under CC BY-NC. No commercial re-use. See rights and permissions. Published by BMJ.

For numbered affiliations see end of article.

Correspondence to

Dr Raul G Nogueira;
raul.g.nogueira@emory.edu

Thanh N Nguyen ,¹ Diogo C Haussen,² Muhammad M Qureshi,³ Hiroshi Yamagami,⁴ Toshiyuki Fujinaka,⁵ Ossama Y Mansour,⁶ Mohamad Abdalkader ,⁷ Michael Frankel,² Zhongming Qiu,⁸ Allan Taylor,⁹ Pedro Lylyk,¹⁰ Omer F Eker,¹¹ Laura Mechtouff ,¹² Michel Piotin,¹³ Fabricio Oliveira Lima,¹⁴ Francisco Mont'Alverne,¹⁵ Wazim Izzath,¹⁶ Nobuyuki Sakai,¹⁷ Mahmoud Mohammaden,² Alhamza R Al-Bayati,² Leonardo Renieri,¹⁸ Salvatore Mangiafico,¹⁸ David Ozretic,¹⁹ Vanessa Chalumeau,²⁰ Saima Ahmad,²¹ Umair Rashid,²¹ Syed Irteza Hussain,²² Seby John,²² Emma Griffin,²³ John Thornton,²³ Jose Antonio Fiorot,²⁴ Rodrigo Rivera,²⁵ Nadia Hammami,²⁶ Anna M Cervantes-Arslanian,²⁷ Hormuzdiyar H Dasenbrock,²⁸ Huynh Le Vu,²⁹ Viet Quy Nguyen,²⁹ Steven Hetts,^{30,31} Romain Bourcier,³² Romain Guile,³² Melanie Walker,³³ Malveeka Sharma,³⁴ Don Frei,³⁵ Pascal Jabbour ,³⁶ Nabeel Herial,³⁶ Fawaz Al-Mufti,³⁷ Atilla Ozcan Ozdemir,³⁸ Ozlem Aykac,³⁸ Dheeraj Gandhi,³⁹ Chandril Chugh,⁴⁰ Charles Matouk,⁴¹ Pascale Lavoie,⁴² Randall Edgell,⁴³ Andre Beer-Furlan,⁴⁴ Michael Chen,⁴⁴ Monika Killer-Oberpfalzer,⁴⁵ Vitor Mendes Pereira,⁴⁶ Patrick Nicholson,⁴⁶ Vikram Huded,⁴⁷ Nobuyuki Ohara,⁴⁸ Daisuke Watanabe,⁴⁹ Dong Hun Shin,⁵⁰ Pedro SC Magalhaes,⁵¹ Raghid Kikano,⁵² Santiago Ortega-Gutierrez,⁵³ Mudassir Farooqui,⁵³ Amal Abou-Hamden,⁵⁴ Tatsuo Amano,⁵⁵ Ryoo Yamamoto,⁵⁶ Adrienne Weeks,⁵⁷ Elena A Cora,⁵⁸ Rotem Sivan-Hoffmann,⁵⁹ Roberto Crosa,⁶⁰ Markus Möhlenbruch,⁶¹ Simon Nagel,⁶² Hosam Al-Jehani,⁶³ Sunil A Sheth,⁶⁴ Victor S Lopez Rivera,⁶⁴ James E Siegler,⁶⁵ Achmad Fidaus Sani,⁶⁶ Ajit S Puri,⁶⁷ Anna Luisa Kuhn,⁶⁷ Gianmarco Bernava,⁶⁸ Paolo Machi,⁶⁸ Daniel G Abud,⁶⁹ Octavio M Pontes-Neto,⁷⁰ Ajay K Wakhloo,⁷¹ Barbara Voetsch,⁷² Eytan Raz,⁷³ Shadi Yaghi,⁷⁴ Brijesh P Mehta,⁷⁵ Naoto Kimura,⁷⁶ Mamoru Murakami,⁷⁷ Jin Soo Lee,⁷⁸ Ji Man Hong,⁷⁸ Robert Fahed,⁷⁹ Gregory Walker,⁷⁹ Eiji Hagashi,⁸⁰ Steve M Cordina,⁸¹ Hong Gee Roh,⁸² Ken Wong,⁸³ Juan F Arenillas,⁸⁴ Mario Martinez-Galdamez,⁸⁵ Jordi Blasco,⁸⁶ Alejandro Rodriguez Vasquez,⁸⁷ Luisa Fonseca,⁸⁸ M Luis Silva,⁸⁹ Teddy Y Wu ,⁹⁰ Simon John,⁹¹ Alex Brehm,⁹² Marios Psychogios,⁹² William J Mack,⁹³ Matthew Tenser,⁹³ Tatemu Todaka,⁹⁴ Miki Fujimura,⁹⁵ Roberta Novakovic,⁹⁶ Jun Deguchi,⁹⁷ Yuri Sugiura,⁹⁸ Hiroshi Tokimura,⁹⁹ Rakesh Khatri,¹⁰⁰ Michael Kelly,¹⁰¹ Lissa Peeling,¹⁰¹ Yuichi Murayama,¹⁰² Hugh Stephen Winters,¹⁰³ Johnny Wong,¹⁰⁴ Mohamed Teleb,¹⁰⁵ Jeremy Payne,¹⁰⁵ Hiroki Fukuda,¹⁰⁶ Kosuke Miyake,¹⁰⁷ Junsuke Shimbo,¹⁰⁸ Yusuke Sugimura,¹⁰⁹ Masaaki Uno,¹¹⁰ Yohei Takenobu,¹¹¹ Yuji Matsumaru,¹¹² Satoshi Yamada,¹¹³ Ryuhei Kono,¹¹⁴ Takuya Kanamaru,¹¹⁵ Masafumi Morimoto,¹¹⁶ Junichi Iida,¹¹⁷ Vasu Saini,¹¹⁸ Dileep Yavagal,¹¹⁸ Saif Bushnaq,¹¹⁹ Wenguo Huang,¹²⁰ Italo Linfante,¹²¹ Jawad Kirmani,¹²² David S Liebeskind,¹²³ Viktor Szeder,¹²⁴ Ruchir Shah,¹²⁵ Thomas G Devlin,¹²⁵ Lee Birnbaum,¹²⁶ Jun Luo,¹²⁷ Anchalee Churojana,¹²⁸ Hesham E Masoud,¹²⁹ Carlos Ynigo Lopez,¹²⁹ Brendan Steinfert,¹³⁰ Alice Ma,¹³⁰ Ameer E Hassan ,¹³¹ Amal Al Hashmi,¹³² Mollie McDermott,¹³³ Maxim Mokin,¹³⁴ Alex Chebl,¹³⁵ Odysseas Kargiotis,¹³⁶ Georgios Tsvigoulis,¹³⁷ Jane G Morris,¹³⁸ Clifford J Eskey,¹³⁹ Jesse Thon,¹⁴⁰ Leticia Rebello,¹⁴⁰ Dorothea Altschul,¹⁴¹ Oriana Cornett,¹⁴² Varsha Singh,¹⁴² Jeyaraj Pandian,¹⁴³ Anirudh Kulkarni,¹⁴³ Pablo M Lavados,¹⁴⁴ Veronica V Olavarria,¹⁴⁴ Kenichi Todo,¹⁴⁵ Yuki Yamamoto,¹⁴⁶

Gisele Sampaio Silva,¹⁴⁷ Serdar Geyik,¹⁴⁸ Jasmine Johann,³⁵ Sumeet Multani,¹⁴⁹ Artem Kaliaev,⁷ Kazutaka Sonoda,¹⁵⁰ Hiroyuki Hashimoto,¹⁵¹ Adel Alhazzani,¹⁵² David Y Chung,²⁷ Stephan A Mayer,³⁷ Johanna T Fifi,¹⁵³ Michael D Hill,¹⁵⁴ Hao Zhang,¹⁵⁵ Zhengzhou Yuan,¹⁵⁶ Xianjin Shang,¹⁵⁷ Alicia C Castonguay,¹⁵⁸ Rishi Gupta,¹⁵⁹ Tudor G Jovin,⁶⁵ Jean Raymond,¹⁶⁰ Osama O Zaidat,¹¹⁹ Raul G Nogueira,² SVIN COVID-19 Registry, the Middle East North Africa Stroke and Interventional Neurotherapies Organization (MENA-SINO), Japanese Society of Vascular and Interventional Neurology Society (JVIN)

ABSTRACT

Background During the COVID-19 pandemic, decreased volumes of stroke admissions and mechanical thrombectomy were reported. The study's objective was to examine whether subarachnoid haemorrhage (SAH) hospitalisations and ruptured aneurysm coiling interventions demonstrated similar declines.

Methods We conducted a cross-sectional, retrospective, observational study across 6 continents, 37 countries and 140 comprehensive stroke centres. Patients with the diagnosis of SAH, aneurysmal SAH, ruptured aneurysm coiling interventions and COVID-19 were identified by prospective aneurysm databases or by International Classification of Diseases, 10th Revision, codes. The 3-month cumulative volume, monthly volumes for SAH hospitalisations and ruptured aneurysm coiling procedures were compared for the period before (1 year and immediately before) and during the pandemic, defined as 1 March–31 May 2020. The prior 1-year control period (1 March–31 May 2019) was obtained to account for seasonal variation.

Findings There was a significant decline in SAH hospitalisations, with 2044 admissions in the 3 months immediately before and 1585 admissions during the pandemic, representing a relative decline of 22.5% (95% CI –24.3% to –20.7%, $p < 0.0001$). Embolisation of ruptured aneurysms declined with 1170–1035 procedures, respectively, representing an 11.5% (95% CI –13.5% to –9.8%, $p = 0.002$) relative drop. Subgroup analysis was noted for aneurysmal SAH hospitalisation decline from 834 to 626 hospitalisations, a 24.9% relative decline (95% CI –28.0% to –22.1%, $p < 0.0001$). A relative increase in ruptured aneurysm coiling was noted in low coiling volume hospitals of 41.1% (95% CI 32.3% to 50.6%, $p = 0.008$) despite a decrease in SAH admissions in this tertile.

Interpretation There was a relative decrease in the volume of SAH hospitalisations, aneurysmal SAH hospitalisations and ruptured aneurysm embolisations during the COVID-19 pandemic. These findings in SAH are consistent with a decrease in other emergencies, such as stroke and myocardial infarction.

BACKGROUND

The COVID-19 pandemic led to the rationing of health-care resources worldwide to accommodate the care of critically ill patients with SARS-CoV-2 infection.¹ Changes in prehospital emergency medical service, emergency room care, acute stroke and subarachnoid haemorrhage (SAH) protocols^{2,3} were reported to conserve resources and to mitigate infection risk to patients and their providers. Decreases in ischaemic stroke admission, rates of intravenous thrombolysis (IVT)^{4–6} and mechanical thrombectomy (MT) volume⁷ were reported in several regions in Europe,^{8,9} Germany,¹⁰ China,¹¹ Brazil¹² and the USA,^{13,14} with steeper declines in stroke hospitalisations seen in areas with higher COVID-19 hospitalisation volume.¹⁵

However, there is a paucity of information on the impact of the COVID-19 pandemic on SAH admissions.

Early regional or single-centre reports from Paris¹⁶ and Toronto¹⁷ suggest a decrease in aneurysmal SAH volumes, whereas no changes were seen in Berlin.¹⁸ We evaluated the impact of COVID-19 on the volumes of SAH admissions and embolisation treatments for patients with ruptured intracranial aneurysms during the height of the first 3 months of the pandemic, defined from 1 March to 31 May 2020.

Study objectives and hypothesis

Our primary hypothesis was that there would be a reduction in SAH hospitalisations and endovascular coil embolisation procedures for ruptured aneurysms during the pandemic, compared with the immediate 3 months prior to the pandemic. Our secondary hypothesis was that there would be a reduction in these volumes compared with a similar calendar period in 2019. The third hypothesis was that the reduction in SAH volume would occur in most centres, including those with low or non-existent COVID-19 hospitalisation burden, but would be more significant in centres with high COVID-19 hospitalisation burden. The fourth hypothesis was that high procedural coiling volume centres would be less impacted by procedural volume changes than low procedural volume centres.

METHODS

Study design

This was a cross-sectional, observational, multicentre, retrospective study of consecutive patients hospitalised with SAH, aneurysmal SAH, non-traumatic SAH and ruptured intracranial aneurysm embolisations.

Setting and participants

Of 175 invited sites, 140 comprehensive stroke centres submitted data from 37 countries across six continents with 5571 patients with SAH and 3473 ruptured aneurysm embolisations across the three different study periods. Monthly and weekly volume of SAH, ruptured aneurysm embolisations and COVID-19 admission volume data were collected over three periods of time: 1 March–31 May 2020 (pandemic months), 1 November 2019–29 February 2020 (immediately preceding the pandemic months) and 1 March–31 May 2019 (equivalent period 1 year prior to the pandemic). The period of recruitment was conducted between 26 May and 30 July 2020. The data were collected on Excel (version 16.45) documents.

Table 1 SAH hospitalisation volumes immediately before and during the COVID-19 pandemic

	Overall volume					Monthly volume				
	N	n1	n2	Relative (%) change % (95% CI)	P value	N	Immediately before n=2838	During COVID-19 n=1645	Difference* (95% CI) Median (IQR)	P value
Overall	118	2044	1585	-22.5 (-24.3 to -20.7)	<0.0001	124	4.5 (2.5–7.1)	3.3 (1.3–6.3)	-0.88 (-1.1 to -0.58)	<0.0001
Hospital COVID-19 volume†										
Low	32	432	367	-15.1 (-18.7 to -12.0)	0.014	33	3.5 (2.5–6.5)	3.3 (1.7–6.0)	-0.83 (-1.9 to 0.50)	0.076
Int	32	589	458	-22.2 (-25.8 to -19.1)	<0.0001	34	4.9 (3.5–6.8)	3.7 (1.7–6.0)	-0.83 (-1.9 to -0.17)	0.001
High	33	731	513	-29.8 (-33.2 to -26.6)	<0.0001	36	6.0 (3.0–8.4)	4.2 (2.2–7.2)	-1.0 (-2.0 to -0.67)	<0.0001
Hospital SAH coil embolisation volume‡										
Low	42	370	293	-20.8 (-25.2 to -17.0)	0.002	45	2.5 (1.3–3.8)	2.0 (1.0–3.3)	-0.25 (-0.75 to 0.08)	0.141
Int	35	490	385	-21.4 (-25.3 to -18.0)	0.0002	36	4.4 (2.9–5.6)	3.0 (1.5–4.7)	-1.0 (-1.5 to -0.17)	0.007
High	35	1014	783	-22.8 (-25.5 to -20.3)	<0.0001	36	7.3 (5.9–11.6)	6.7 (4.0–9.3)	-2.0 (-3.1 to -0.75)	<0.0001

n1 is based on 3 months before the pandemic (December 2019–February 2020). Immediately before is based on 4 months before the pandemic (November 2019–February 2020). n2 and during COVID-19 are based on March 2020–May 2020.

P value is from Poisson means test (overall volume analysis) and Wilcoxon signed-rank test (monthly volume analysis).

*Difference denotes the median difference between the two time periods.

†P value: low versus Int=0.004, low versus high=<0.0001, Int versus high=0.002.

‡P value: low versus Int=0.831, low versus high=0.429, Int versus high=0.541.

Int, intermediate; N, number of hospitals; n, number of admissions; SAH, subarachnoid haemorrhage.

Data were collected from collaborators of the Society of Vascular and Interventional Neurology, the Middle East North Africa Stroke and Interventional Neurotherapies Organisation, the Japanese Interventional Neurology Society and several academic partners. The following countries were represented (number of centres): USA (45), Japan (30), China (6), Brazil (6), Canada (6), France (4), Australia (3), Korea (3), India (3), Chile (2), Spain (2), Switzerland (2), England (2), Saudi Arabia (2), Turkey (2), Austria (1), Argentina (1), Egypt (1), Germany (1), Vietnam (1), Croatia (1), Greece (1), Indonesia (1), Ireland (1), Israel (1), Italy (1), Lebanon (1), New Zealand (1), Oman (1), Pakistan (1), Portugal (1), Qatar (1), South Africa (1), Thailand (1), Tunisia (1), United Arab Emirates (1) and Uruguay (1).

Study variables and outcome measures

SAH data were obtained by a prospectively maintained aneurysm or stroke databases at each comprehensive stroke centre or by International Classification of Diseases, 10th Revision (ICD-10) codes (primary, secondary or tertiary discharge codes) with verification by a physician or coordinator. The following ICD-10 codes were used: I60 (non-traumatic SAH), I60.0 (non-traumatic SAH from carotid siphon and bifurcation), I60.1 (non-traumatic SAH from middle cerebral artery), I60.2 (non-traumatic SAH from anterior communicating artery), I60.3 (non-traumatic SAH from posterior communicating artery), I60.4 (non-traumatic SAH from basilar artery), I60.5 (non-traumatic SAH from vertebral artery), I60.6 (non-traumatic SAH from other intracranial arteries), I60.7 (non-traumatic SAH from intracranial artery, unspecified) I60.8 (other non-traumatic SAH) and I60.9 (non-traumatic SAH unspecified).

Subgroup analysis of confirmed aneurysmal SAH hospitalisations and non-traumatic SAH were performed. Aneurysmal SAH was defined as SAH related to a ruptured intracranial aneurysm. Non-traumatic SAH was defined as SAH unrelated to traumatic causes but could include SAH secondary to aneurysmal, arteriovenous malformation (AVM), perimesencephalic or other causes. The volume of embolisations of ruptured intracranial aneurysms was also retrieved.

COVID-19 hospitalisation was defined as a patient admitted with COVID-19 diagnosis, inclusive of non-neurological diagnosis. Monthly and weekly volumes of COVID-19 hospitalisation were collected from 1 March to 31 May 2020.

Low, intermediate and high procedural volume centres were categorised according to monthly coiling of ruptured aneurysm volume data received of the 4 months immediately preceding the pandemic (1 November 2019–29 February 2020, inclusive) and divided into tertiles: low volume, <1.25; intermediate volume, >1.25–<3.0; and high volume, >3 coiling cases per month. COVID-19 hospitalisation volumes were based on mean monthly volume data received and were divided into tertiles: low volume, <10.6; intermediate volume, >10.6–<103.6; and high volume, >103.6 hospitalisations per month.

Bias

A second control period (1 March–31 May 2019) was included to account for seasonal variation. To reduce the risk of bias, centres with incomplete data were excluded from the subgroup analysis in which the data were missing.

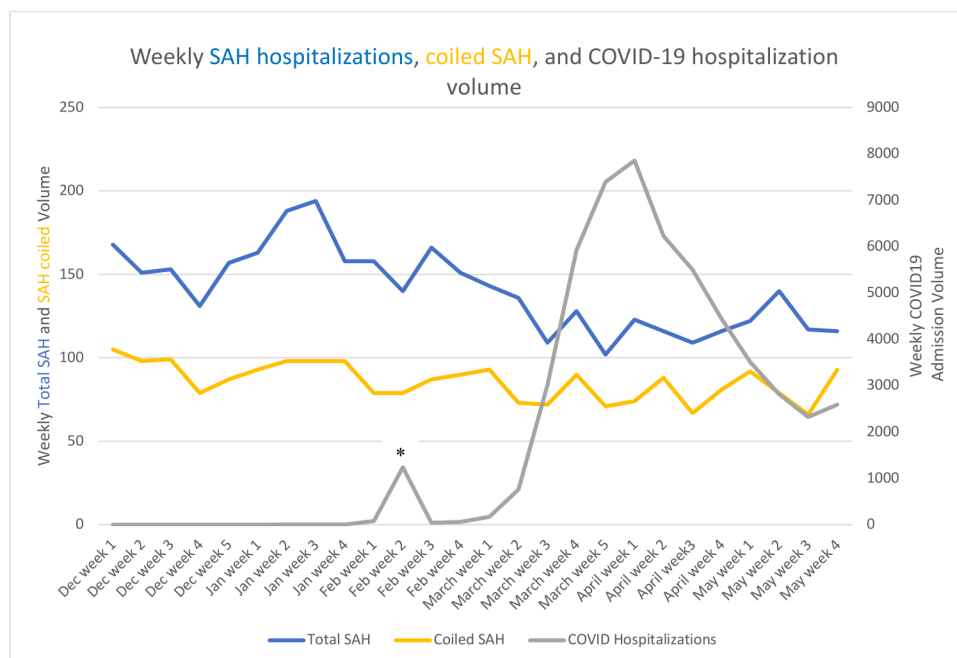


Figure 1 *Peak of 1235 COVID-19 hospitalisations in the second week of February, predominantly from one hospital in Wuhan, China. SAH, subarachnoid haemorrhage.

Statistical analysis

The monthly volumes for the ruptured aneurysm coil embolisation procedure and SAH admissions were compared for the period before (1 year and immediately before) and during the COVID-19 pandemic. The normality of the data was tested with the Shapiro-Wilk test. The data were determined to be non-normal and were therefore presented as median (IQR). The non-parametric Wilcoxon signed-rank test was applied to compare differences in monthly volume between two time periods. The analyses were repeated in the setting of low, intermediate and high COVID-19 and procedural volume hospitals.

We further looked at the percentage change in the number of procedures and SAH admissions, aneurysmal SAH admissions, and non-traumatic SAH admissions before and during the COVID-19 pandemic. For this analysis, we restricted the immediately before group to 3 months before the pandemic (1 December 2019–29 February 2020) to keep it consistent with the COVID-19 group. The 95% CIs for percentage change were calculated using the Wilson procedure without correction for continuity. The differences in the number of procedures and admissions across the two periods were assessed for significance using the Poisson means test. The relative percentage decrease in volume between low-volume, intermediate-volume and high-volume hospitals was tested using the z-test of proportion.

We performed a supplementary analysis comparing monthly volumes and percentage change in the number of ruptured aneurysm coiling procedures and SAH hospitalisations across different world regions. All

data were analysed using SAS V.9.4, and the significance level was set at a p value of <0.05.

This study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.¹⁹

FINDINGS

A total of 1088, 2044 and 1585 SAH hospitalisations (overall n=4717) and 719, 1170 and 1035 coiling procedures for ruptured aneurysms (overall n=2924) were included across the 3-month prior year periods, 3 months immediately prepandemic and 3 months pandemic, respectively. These were distributed across 140 comprehensive stroke centres, 37 nations and 6 continents. The Shapiro-Wilk test revealed that the normality of the data was non-normal.

Subarachnoid hemorrhage hospitalisation volumes

In the primary analysis, 118 centres submitted data on SAH volume with a total of 2044 admissions in the 3 months immediately before and 1585 admissions during the 3 months of the pandemic, representing a relative volume decline of 22.5% (95% CI –24.3% to –20.7%, $p < 0.0001$). Monthly SAH admission volumes also demonstrated a relative decline before and during the pandemic months (median, 4.5 (IQR 2.5–7.1) vs 3.3 (IQR 1.3–6.3); $p < 0.0001$) (table 1 and figure 1).

In the secondary analysis, 75 centres contributed data with SAH monthly volumes 1 year prior (table 2). There were 1088 before, compared with 900 SAH admissions during the pandemic, representing a 17.3% relative decline (95% CI, –19.6 to –15.2, $p < 0.0001$). The

Table 2 SAH volumes 1 year before and during the COVID-19 pandemic

	Overall volume					Monthly volume			P value	
	N	n1	n2	Relative (%) change % (95% CI)	P value	N	During COVID-19			
							1 year before	Median (IQR)		Difference* (95% CI)
SAH	75	1088	900	-17.3 (-19.6 to -15.2)	<0.0001	75	3.0 (2.0-6.3)	2.7 (1.3-5.7)	-0.33 (-1.0 to 0.0)	0.001
Coil embolisation†	83	719	652	-9.3 (-11.7 to -7.4)	0.071	85	1.7 (0.67-3.7)	1.3 (0.67-2.7)	0.0 (-0.33 to 0.0)	0.197

n1 and 1 year before are based on 3-month data 1 year before the pandemic (March 2019–May 2019). n2 and during COVID-19 are based on data from March 2020 to May 2020. P value is from Poisson means test (overall volume analysis) and Wilcoxon signed-rank test (monthly volume analysis).

*Difference denotes the median difference between the two time periods.

†85 centres contributed 728 and 655 patients to 1 year before and during the COVID-19 period in the monthly volume analysis. n, number of admissions/procedures; N, number of hospitals; SAH, subarachnoid haemorrhage.

median monthly SAH admission volume declined from a median of 3.0 [IQR, 2.0–6.3] in the corresponding period of the prior year to 2.7 [IQR, 1.3–5.7, $p=0.001$] over the first 3 months of the pandemic.

In subgroup analysis, 56 centres confirmed aneurysmal SAH admissions data in the 3 months immediately before and during the pandemic. There was a relative decline from 834 to 626 hospitalisations, representing a 24.9% relative decline (95% CI -28.0% to -22.1%, $p<0.0001$). Additionally, 37 centres confirmed aneurysmal SAH admissions data in the 1-year prior control period, also noted for a relative decline from 435 to 370 hospitalisations, representing a 14.9% relative decline (95% CI -18.6 to -11.9, $p=0.022$) (table 3).

Non-traumatic SAH admissions had parallel relative declines both in the immediately before (-24.6%, 95% CI -26.9% to -22.5%, $p<0.0001$, $n=85$ centres) and 1-year before periods (-15.6%, 95% CI -18.4% to -13.1%, $p=0.002$, $n=53$ centres) (table 3).

Declines in SAH hospitalisation volumes were significant in Asia, with a relative decrease of 24.7% (95% CI -28.0% to -21.7%, $p<0.0001$, $n=47$ centres); North America, with a relative decrease of 21.0% (95% CI -24.0% to -18.3%, $p<0.0001$, $n=46$ centres); Europe, with a relative decrease of 29.0% (95% CI -35.3% to -23.5%, $p=0.001$, $n=11$ centres); South America, with a relative decrease of 21.5% (95% CI -27.4% to -16.6%, $p=0.012$, $n=8$ centres). In contrast, no significant change was noted in Oceania or Africa. (online supplemental table 1). Country-specific relative changes in SAH hospitalisation volumes are represented in online supplemental table 3 and online supplemental figure 1).

SAH aneurysm embolisation volumes

In the primary analysis, 125 centres submitted data on ruptured aneurysm embolisation volumes with a total of 1170 procedures in the 3 months immediately before and 1035 procedures performed during the 3 months of the pandemic, representing a relative drop of 11.5% (95% CI -13.5% to -9.8%, $p=0.002$). Median monthly embolisation volumes demonstrated a relative decline compared with the same periods immediately preceding (median, 1.8 (IQR 1–4) vs 1.7 (IQR 0.67–3.3); $p=0.0004$) (table 4 and figure 1).

In the secondary analysis, 83 centres contributed data for ruptured aneurysm coiled volumes during the pandemic and 1 year previously. Ruptured aneurysm embolisations also declined numerically between the calendar year, 719 vs 652 procedures, with a 9.3% (95% CI -11.7% to -7.4%, $p=0.07$) relative drop in volumes (table 2). No significant change was noted in the median monthly volume ($p=0.197$).

During the pandemic, ruptured aneurysm coiling volume was decreased in Asia with a 20.5% relative decline (95% CI -24.9% to -16.6%, $p=0.003$, $n=52$ centres), decreased in Europe with a 15.3% relative decline (95% CI -20.4% to -11.3%, $p=0.06$, $n=14$

Table 3 Aneurysmal SAH, non-traumatic SAH hospitalisations before and during the pandemic

	Immediately before and during the pandemic				1 year before and during the pandemic					
	N	n1	n2	Relative change % (95% CI)	P value	N	n1	n2	Relative change % (95% CI)	P value
Aneurysmal SAH	56	834	626	-24.9 (-28.0 to -22.1)	<0.0001	37	435	370	-14.9 (-18.6 to -11.9)	0.022
Non-traumatic SAH*	85	1451	1094	-24.6 (-26.9 to -22.5)	<0.0001	53	744	628	-15.6 (-18.4 to -13.1)	0.002

n1 immediately before the pandemic is based on 3-month data from December 2019 to February 2020. n2 1 year before is based on 3-month data from March 2019 to May 2019. n is based on 3-month control data during the COVID-19 from March 2020 to May 2020 for both analyses. P value is from the Poisson means test.

*Non-traumatic SAH include aneurysms and perimesencephalic SAH. n, number of admissions; N, number of hospitals; SAH, subarachnoid haemorrhage.

centres) and increased in Oceania by 77.8% (95% CI 54.8 to 91.0, $p=0.06$, $n=4$ centres), whereas no significant change in volume was noted in North America, South America nor Africa (online supplemental table 2). Country-specific relative changes in ruptured aneurysm coiling volumes are represented in online supplemental table 3 and online supplemental figure 2.

COVID-19 hospitalisation volume, SAH hospitalisation and ruptured aneurysm embolisation volumes in relation to the pandemic

Figure 1 depicts the weekly number of SAH hospitalisations, ruptured aneurysm coiling and COVID-19 hospitalisation volumes. Across the tertiles of COVID-19 hospitalisation volume, high-volume COVID-19 centres (-29.8%, 95% CI -33.2% to -26.6%) were significantly more vulnerable to declines in SAH hospitalisation volumes than low-volume COVID-19 centres (-15.1%, 95% CI -18.7% to -12.0%; $p<0.0001$) (table 1).

Similarly, there was a gradient for greater decrease in ruptured aneurysm embolisation in high-volume COVID-19 centres (-22.2%, 95% CI -27.0% to -18.0%) compared with intermediate-volume (-10.0%, 95% CI -13.8% to -7.2%, $p<0.0001$) and low-volume (-1.5%, 95% CI -3.7% to -0.6%, $p<0.001$) COVID-19 centres (table 4).

Ruptured aneurysm procedural volumes, SAH hospitalisation and ruptured aneurysm embolisation volumes in relation to the pandemic

There were declines in SAH hospitalisation volume across the three tertiles of high (-22.8%, 95% CI -25.5% to -20.3%, $p<0.0001$), intermediate (-21.4%, 95% CI -25.3% to -18.0%, $p=0.0002$) and low (-20.8% 95% CI -25.2% to -17.0%, $p=0.002$) SAH procedural volume centres, with no differences in decline seen between the three tertiles (table 1).

Similarly, ruptured aneurysm embolisation volume declines were noted in high (-18.2%, 95% CI -20.9% to -15.8%, $p<0.0001$) procedural volume centres. However, in hospitals with low tertile procedural volumes, there was an increase noted in the coiling of the ruptured aneurysm during the pandemic of 41% (95% CI 32.3% to 50.6%, $p=0.008$) (table 4).

DISCUSSION

We noted a decrease in the volume of SAH hospitalisations, aneurysmal SAH hospitalisations and embolisation of ruptured aneurysms during the first 3 months of the COVID-19 pandemic compared with the immediate prior months. Compared with the corresponding period in the prior year, there was a significant reduction in SAH hospitalisation volume, but no change was noted in the number of embolisation procedures for ruptured aneurysms. To our knowledge, this is the first report of a multicentre decrease in volumes for SAH hospitalisations, aneurysmal SAH hospitalisations and embolisation procedures for ruptured intracranial aneurysm during the COVID-19

Table 4 SAH coil embolisation volumes immediately before and during the COVID-19 pandemic

N	n1	n2	Overall volume			Monthly volume			P value	
			Relative (%) change % (95% CI)	P value	N	Immediately before n=1670	During COVID-19 n=1075	Difference* (95% CI)		
										Median (IQR)
Overall	125	1170	1035	-11.5 (-13.5 to -9.8)	0.002	133	1.8 (1.0-4.0)	1.7 (0.67-3.3)	-0.25 (-0.58 to -0.08)	0.0004
Hospital COVID-19 volume†										
Low	39	270	266	-1.5 (-3.7 to -0.58)	0.764	40	1.5 (0.88-2.5)	1.0 (0.50-2.8)	-0.29 (-0.67 to 0.08)	0.294
Int	33	319	287	-10.0 (-13.8 to -7.2)	0.151	35	2.5 (1.0-3.8)	2.0 (1.0-3.0)	-0.25 (-0.75 to 0.0)	0.041
High	31	329	256	-22.2 (-27.0 to -18.0)	0.002	34	2.0 (1.3-5.0)	2.0 (1.0-4.0)	-0.63 (-1.2 to 0.0)	0.007
Hospital SAH Coil embolisation volume‡										
Low	46	107	151	41.1 (32.3 to 50.6)	0.008	49	0.75 (0.25-1.0)	0.67 (0.33-1.7)	0.0 (0.0 to 0.33)	0.044
Int	37	217	192	-11.5 (-16.5 to -7.9)	0.178	39	2.0 (1.8-2.5)	1.3 (0.67-2.7)	-0.75 (-1.1 to -0.08)	0.015
High	42	846	692	-18.2 (-20.9 to -15.8)	<0.0001	45	5.3 (4.0-8.8)	4.7 (2.7-6.3)	-1.8 (-2.3 to -0.67)	<0.0001

n1 is based on 3 months before the pandemic (December 2019–February 2020). Immediately before is based on 4 months before the pandemic (November 2019–February 2020). n2 and during COVID-19 are based on March 2020–May 2020.

P value is from Poisson means test (overall volume analysis) and Wilcoxon signed-rank test (monthly volume analysis).

*Difference denotes the median difference between the two time periods.

†P value: low versus Int≤0.0001, low versus high≤0.0001, Int versus high≤0.0001.

‡P value: low versus Int=n/a; low versus high=n/a; Int versus high=0.019.

Int, intermediate; N, number of hospitals; n, number of procedures; n/a, not applicable; SAH, subarachnoid haemorrhage.

pandemic. Our findings are similar to reported decreases in SAH city-wide in Paris during a 2-week period of the pandemic¹⁶ and decreases in a Toronto hospital,¹⁷ whereas Berlin and Joinville, South Brazil, reported no decreases in SAH during the COVID-19 pandemic.^{12 18}

As expected, hospitals with higher tertiles of COVID-19 hospitalisation burden were more vulnerable to the decline in SAH admissions and ruptured aneurysm coiling volume. However, hospitals with lower COVID-19 hospitalisation burden also demonstrated decreases in SAH admissions, suggesting that access to hospital care was likely not a principal factor to explain the decrease.

High and intermediate procedural volume centres were more affected by declines in SAH hospitalisations and ruptured aneurysm embolisation than low-volume SAH coiling centres during the pandemic. In contrast, hospitals with low SAH coiling volumes at baseline demonstrated an increase in the coiling of ruptured aneurysms during the pandemic despite a significant decrease in total SAH admissions within this tertile of hospitals. An increase in ruptured aneurysm embolisations was observed in another recent multicentre study during the COVID-19 pandemic.²⁰ This suggests a shift towards treating more patients with ruptured aneurysms with endovascular techniques during the pandemic, possibly to mitigate risks of perioperative infection to the patient and/or provider.

These findings of decreases in SAH volumes, including embolisation of ruptured aneurysms, are similar to reports of decreases in stroke admissions, intravenous thrombolysis, MT and acute ST-elevation myocardial infarction (STEMI) activations during the COVID-19 pandemic.^{10 13 21} As postulated with reasons for the decline in stroke admissions in the stroke literature,⁸ patients with milder presentations of aneurysmal SAH may be afraid to present to a hospital due to fear of contracting SARS-CoV-2 infection.

This analysis's strength is the aggregate volume of data worldwide across diverse geography, allowing a high volume or sample size. We used two control periods for comparison; the immediately preceding 3 months and the same 3 months a year ago, to account for potential seasonal variations that may occur in the presentation of SAH.²²

Study limitations

This study's limitations are that while our cohort of centres inform an international, multicentre experience, it is not comprehensive without source data from national databases to account for regional differences in health systems of care. The diagnosis of SAH was obtained using ICD-10 codes in some centres. We cannot exclude the possibility of traumatic SAH. To differentiate from this possibility, we performed a subgroup analysis of confirmed aneurysmal SAH and non-traumatic SAH admissions and found similar relative declines in both control periods. Most centres contributing to these data have systems in place to track SAH admissions and coiling volumes; hence, the relative changes in volume from this

analysis are likely robust. Details on patient SAH presentation grade, clinical outcomes and clipping volume were not collected as they were outside the scope of the study.

Our study definition of the beginning of the pandemic relates to the WHO designation on 11 March 2020. However, regions affected by the pandemic earlier, such as China, met the nadir of their SAH volumes prior to starting our defined pandemic period. As endovascular coiling remains unavailable in many low-income and lower-income to middle-income countries, specific geographical regions were not well represented (ie, Central Africa) in our study. Another shortcoming in selection bias is that several countries in which endovascular coiling is available were not represented in this study (ie, Eastern Europe, South America, Central America and Asia).

INTERPRETATION

In conclusion, there was a relative decrease in the volume of SAH hospitalisations, aneurysmal SAH hospitalisations and ruptured aneurysm embolisation treatments during the first 3 months studied of the COVID-19 pandemic. There were steeper relative declines in SAH hospitalisations and SAH coiling volume in hospitals with higher COVID-19 volume. Among low-volume coiling SAH hospitals, there was a shift towards an increase in ruptured aneurysm coiling. These findings can inform regional neuroscience centres' preparedness^{2 23 24} in the face of a potential second wave or resurgence of COVID-19.

Author affiliations

- ¹Neurology, Radiology, Boston Medical Center, Boston, Massachusetts, USA
- ²Neurology, Marcus Stroke & Neuroscience Center, Grady Memorial Hospital, Emory University School of Medicine, Atlanta, GA, USA
- ³Radiology, Radiation Oncology, Boston University School of Medicine, Boston, Massachusetts, USA
- ⁴Neurology, National Hospital Organization Osaka National Hospital, Osaka, Japan
- ⁵Neurosurgery, National Hospital Organization Osaka National Hospital, Osaka, Japan
- ⁶Neurology, Alexandria University, Alexandria, Egypt
- ⁷Radiology, Boston Medical Center, Boston, Massachusetts, USA
- ⁸Department of Neurology, Xinqiao Hospital, Chongqing, China
- ⁹Neurosurgery, University of Cape Town, Rondebosch, Western Cape, South Africa
- ¹⁰Neurosurgery, Interventional Neuroradiology, Clinica La Sagrada Familia, Buenos Aires, Argentina
- ¹¹Neuroradiologie, Neurologie Vasculaire, Hospices Civils de Lyon, Lyon, Auvergne-Rhône-Alpes, France
- ¹²Neurologie Vasculaire, Hospices Civils de Lyon, Lyon, Auvergne-Rhône-Alpes, France
- ¹³Interventional Neuroradiology, Fondation Ophtalmologique Adolphe de Rothschild, Paris, Île-de-France, France
- ¹⁴Neurology, Hospital Geral de Fortaleza, Fortaleza, Brazil
- ¹⁵Interventional Neuroradiology, Hospital Geral de Fortaleza, Fortaleza, Brazil
- ¹⁶Neuroradiology, Nottingham University Hospitals NHS Trust, Nottingham, UK
- ¹⁷Department of Neurosurgery, Kobe City Medical Center General Hospital, Kobe, Hyogo, Japan
- ¹⁸Interventional Neurovascular Unit, University Hospital Careggi, Firenze, Toscana, Italy
- ¹⁹Neuroradiology, University Hospital Centre Zagreb, Zagreb, Croatia
- ²⁰Interventional Neuroradiology, Hopital Bicetre, Le Kremlin-Bicetre, France
- ²¹Stroke and Interventional Neuroradiology, Lahore General Hospital, Lahore, Pakistan
- ²²Neurological Institute, Cleveland Clinic Abu Dhabi, Abu Dhabi, UAE

- ²³Department of Radiology, Beaumont Hospital, Dublin, Ireland
- ²⁴Neurology, Stroke Unit, Hospital-Estadual Central, Vitoria, Brazil
- ²⁵Neuroradiology, Instituto de Neurocirugia Dr Asengo, Santiago, Chile
- ²⁶Interventional Neuroradiology, Institut National de Neurologie, Tunis, Tunisia
- ²⁷Neurology, Boston Medical Center, Boston, Massachusetts, USA
- ²⁸Neurosurgery, Boston Medical Center, Boston, MA, USA
- ²⁹Stroke Center, Hue Central Hospital, Hue, Thua Thien Hue, Vietnam
- ³⁰Radiology, University of California San Francisco, San Francisco, California, USA
- ³¹Interventional Neuroradiology, University of California San Francisco, San Francisco, California, USA
- ³²Neuroradiologie Diagnostique et Interventionnelle, Hôpital Guillaume & René Laennec, CHU Nantes, Nantes, France
- ³³Neurological Surgery, University of Washington School of Medicine, Seattle, Washington, USA
- ³⁴Neurology, University of Washington School of Medicine, Seattle, Washington, USA
- ³⁵Radiology, Swedish Medical Center, Englewood, Colorado, USA
- ³⁶Neurosurgery, Thomas Jefferson University Hospital, Philadelphia, Pennsylvania, USA
- ³⁷Neurology, Neurosurgery, Westchester Medical Center Health Network, Valhalla, New York, USA
- ³⁸Stroke and Neurointervention Unit, Eskisehir Osmangazi University, Eskisehir, Turkey
- ³⁹Radiology, Neurology, Neurosurgery, University of Maryland School of Medicine, Baltimore, Maryland, USA
- ⁴⁰Interventional Neurology, MAX Superspecialty Hospital, Saket, New Delhi, India
- ⁴¹Neurosurgery, Yale School of Medicine, New Haven, Connecticut, USA
- ⁴²Neurosurgery, Centre Hospitalier Universitaire de Québec-Université Laval, Quebec, Canada
- ⁴³Neurology, St Louis University School of Medicine, St Louis, Missouri, USA
- ⁴⁴Neurological Surgery, Rush University Medical Center, Chicago, IL, USA
- ⁴⁵Neurology, Research Institute of Neurointervention, University Hospital Salzburg / Paracelsus Medical University, Salzburg, Austria
- ⁴⁶Neurosurgery, Medical Imaging, Surgery, University of Toronto, Toronto, Ontario, Canada
- ⁴⁷Neurology, NH Mazumdar Shah Medical Center, Bangalore, India
- ⁴⁸Neurology, Kobe City Medical Center General Hospital, Kobe, Hyogo, Japan
- ⁴⁹Stroke and Neurovascular Surgery, IMS Tokyo-Katsushika General Hospital, Tokyo, Japan
- ⁵⁰Gachon University, Seongnam, Korea (the Republic of)
- ⁵¹Stroke Unit, Hospital Municipal Sao Jose, Joinville, Santa Catarina, Brazil
- ⁵²Interventional Neuroradiology, Lau Medical Center, Beirut, Lebanon
- ⁵³Neurology, University of Iowa Hospitals and Clinics, Iowa City, Iowa, USA
- ⁵⁴Neurosurgery, Royal Adelaide Hospital, Adelaide, South Australia, Australia
- ⁵⁵Stroke and Cerebrovascular Medicine, Kyorin University, Mitaka, Tokyo, Japan
- ⁵⁶Neurology, Yokohama Brain and Spine Center, Yokohama, Japan
- ⁵⁷Neurosurgery, Dalhousie University, Halifax, Nova Scotia, Canada
- ⁵⁸Radiology, QEII Health Sciences Centre, Dalhousie University, Dalhousie, Nova Scotia, Canada
- ⁵⁹Interventional Neuroradiology, Rambam Health Care Campus, Haifa, Haifa, Israel
- ⁶⁰Centro Endovascular Neurologico Medica Uruguay, Montevideo, Uruguay
- ⁶¹Neuroradiology, Heidelberg University Hospital, Heidelberg, Baden-Württemberg, Germany
- ⁶²Neurology, Heidelberg University Hospital, Heidelberg, Baden-Württemberg, Germany
- ⁶³Neurosurgery, Interventional Radiology and Critical Care Medicine, King Fahad Hospital of the University, Imam Abdulrahman bin Faisal University, Alkhubar, Saudi Arabia
- ⁶⁴Neurology, University of Texas McGovern Medical School, Houston, Texas, USA
- ⁶⁵Neurology, Cooper University Hospital, Cooper Medical School of Rowan University, Camden, New Jersey, USA
- ⁶⁶Airlangga University, Surabaya, Jawa Timur, Indonesia
- ⁶⁷Neurointerventional Radiology, University of Massachusetts Medical School, Worcester, Massachusetts, USA
- ⁶⁸Interventional Neuroradiology, University Hospitals Geneva, Geneva, Switzerland
- ⁶⁹Interventional Neuroradiology, Ribeirão Preto Medical School, University of São Paulo, São Paulo, Brazil
- ⁷⁰Neuroscience and Behavioral Sciences, Ribeirão Preto Medical School, University of São Paulo, São Paulo, Brazil
- ⁷¹Interventional Neuroradiology, Beth Israel Lahey Health, Burlington, Massachusetts, USA
- ⁷²Neurology, Beth Israel Lahey Health, Burlington, Massachusetts, USA
- ⁷³Radiology, NYU Langone Health, NYU Grossman School of Medicine, New York, New York, USA
- ⁷⁴Neurology, NYU Langone Health, NYU Grossman School of Medicine, New York, New York, USA
- ⁷⁵Memorial Neuroscience Institute, Pembroke Pines, Florida, USA
- ⁷⁶Neurosurgery, Iwate Prefectural Central Hospital, Morioka, Iwate, Japan
- ⁷⁷Neurosurgery, Kyoto Second Red Cross Hospital, Kyoto, Japan
- ⁷⁸Ajou University Hospital, Suwon, Gyeonggi-do, South Korea
- ⁷⁹Neurology, University of Ottawa, Ottawa, Ontario, Canada
- ⁸⁰Cerebrovascular Medicine, Saga-ken Medical Centre Koseikan, Saga, Japan
- ⁸¹Neurology, Neurosurgery, Radiology, University of South Alabama, Mobile, Alabama, USA
- ⁸²Konkuk University, Gwangjin-gu, Seoul, South Korea
- ⁸³Interventional Neuroradiology, Royal London Hospital, Barts Health NHS Trust, London, UK
- ⁸⁴Neurology, Hospital Clinico Universitario de Valladolid, Valladolid, Castilla y León, Spain
- ⁸⁵Interventional Neuroradiology, Hospital Clínico Universitario, Universidad de Valladolid, Valladolid, Spain
- ⁸⁶NR, Hospital Clinic de Barcelona, Barcelona, Catalunya, Spain
- ⁸⁷Neurology, Hospital Clinic de Barcelona, Barcelona, Catalunya, Spain
- ⁸⁸Stroke Unit, Department of Medicine, Centro Hospitalar Universitário de São João, Porto, Portugal
- ⁸⁹Neuroradiology, Centro Hospitalar Universitário de São João, Porto, Portugal
- ⁹⁰Neurology, Christchurch Hospital, Christchurch, New Zealand
- ⁹¹Neurosurgery, Christchurch Hospital, Christchurch, New Zealand
- ⁹²Interventional and Diagnostic Neuroradiology, University Hospital Basel, Basel, Switzerland
- ⁹³Neurosurgery, University of Southern California, Los Angeles, California, USA
- ⁹⁴Neurosurgery, Japanese Red Cross Kumamoto Hospital, Kumamoto, Kumamoto, Japan
- ⁹⁵Neurosurgery, Kohnan Hospital, Sendai, Miyagi, Japan
- ⁹⁶Radiology, Neurology, UT Southwestern, Dallas, Texas, USA
- ⁹⁷Endovascular Neurosurgery, Nara City Hospital, Nara, Nara, Japan
- ⁹⁸Neurology, Toyonaka Municipal Hospital, Toyonaka, Osaka, Japan
- ⁹⁹Neurosurgery and Stroke Center, Kagoshima City Hospital, Kagoshima, Kagoshima, Japan
- ¹⁰⁰Texas Tech University System, Lubbock, Texas, USA
- ¹⁰¹Neurosurgery, University of Saskatchewan, Saskatoon, Saskatchewan, Canada
- ¹⁰²Neurosurgery, Jikei University School of Medicine, Minato-ku, Tokyo, Japan
- ¹⁰³Neurology, Royal Prince Alfred Hospital, Camperdown, New South Wales, Australia
- ¹⁰⁴Neurosurgery, Royal Prince Alfred Hospital, Camperdown, New South Wales, Australia
- ¹⁰⁵Neurosciences, Banner Desert Medical Center, Mesa, Arizona, USA
- ¹⁰⁶Neurology, Japanese Red Cross Matsue Hospital, Shimane, Japan
- ¹⁰⁷Neurology, Shiroyama Hospital, Habikino, Osaka, Japan
- ¹⁰⁸Cerebrovascular Medicine, Niigata City General Hospital, Niigata, Niigata, Japan
- ¹⁰⁹Neurology, Sugimura Hospital, Kumamoto, Japan
- ¹¹⁰Department of Neurosurgery, Kawasaki Medical School, Kurashiki, Japan
- ¹¹¹Neurology, Osaka Red Cross Hospital, Osaka, Japan
- ¹¹²Neurosurgery, University of Tsukuba, Tsukuba, Ibaraki, Japan
- ¹¹³Neurology, Stroke Center and Neuroendovascular Therapy, Saiseikai Central Hospital, Minato-ku, Tokyo, Japan
- ¹¹⁴Neurology, Kinikyo Chuo Hospital, Sapporo, Hokkaido, Japan
- ¹¹⁵Cerebrovascular Medicine, NTT Medical Center Tokyo, Tokyo, Japan
- ¹¹⁶Neurosurgery, Yokohama Shintoshin Neurosurgical Hospital, Yokohama, Japan
- ¹¹⁷Neurosurgery, Osaka General Medical Center, Osaka, Japan
- ¹¹⁸Neurology, Neurosurgery, University of Miami School of Medicine, Miami, Florida, USA
- ¹¹⁹Neurology, Bon Secours Mercy Health System, Toledo, Ohio, USA
- ¹²⁰Neurology, Maoming City Hospital, Guandong, China
- ¹²¹Interventional Neuroradiology, Endovascular Neurosurgery, Miami Cardiac & Vascular Institute, Miami, Florida, USA
- ¹²²Neurology, Hackensack Meridian Health, Edison, New Jersey, USA
- ¹²³Neurology, University of California Los Angeles, Los Angeles, California, USA

- ¹²⁴Interventional Neuroradiology, University of California Los Angeles, Los Angeles, California, USA
- ¹²⁵Neurology, Erlanger Medical Center, University of Tennessee, Chattanooga, Tennessee, USA
- ¹²⁶Neurology, Neurosurgery, Radiology, University of Texas Health San Antonio, San Antonio, Texas, USA
- ¹²⁷Neurology, Mianyang 404 Hospital, Mianyang, Sichuan, China
- ¹²⁸Radiology, Siriraj Hospital, Mahidol University, Bangkok, Thailand
- ¹²⁹Neurology, Neurosurgery, Radiology, SUNY Upstate Medical University, Syracuse, New York, USA
- ¹³⁰Neurosurgery, Royal North Shore Hospital, Sydney, New South Wales, Australia
- ¹³¹Neurosciences, The University of Texas Rio Grande Valley, Harlingen, Texas, USA
- ¹³²Central Stroke Unit, Directorate of Neuroscience, Khoula Hospital, Ministry of Health, Muscat, Oman
- ¹³³Neurology, University of Michigan, Ann Arbor, Michigan, USA
- ¹³⁴Neurosurgery, University of South Florida, Tampa, Florida, USA
- ¹³⁵Neurology, Henry Ford Health System, Detroit, Michigan, USA
- ¹³⁶Stroke Unit, Metropolitan Hospital, Piraeus, Greece
- ¹³⁷Faculty of Medicine, National and Kapodistrian University of Athens, Athens, Greece
- ¹³⁸Neurology, Maine Medical Center, Portland, Maine, USA
- ¹³⁹Neuroradiology, Dartmouth Hitchcock Medical Center, Lebanon, New Hampshire, USA
- ¹⁴⁰Neurology, Hospital Universitario de Brasilia, Brasilia, Distrito Federal, Brazil
- ¹⁴¹Neurointerventional Neurosurgery, The Valley Hospital, Ridgewood, New Jersey, USA
- ¹⁴²Neurosciences, Stroke Program, St Joseph's University Medical Center, Paterson, New Jersey, USA
- ¹⁴³Neurology, Christian Medical College and Hospital Ludhiana, Ludhiana, Punjab, India
- ¹⁴⁴Vascular Neurology Unit, Clínica Alemana, Universidad del Desarrollo, Santiago, Chile
- ¹⁴⁵Neurology, Osaka University Graduate School of Medicine, Osaka, Japan
- ¹⁴⁶Neurology, Tokushima University Hospital, Tokushima, Japan
- ¹⁴⁷Neurology, Universidade Federal de Sao Paulo, Sao Paulo, Sao Paulo, Brazil
- ¹⁴⁸Istanbul Aydin University, Istanbul, Istanbul, Turkey
- ¹⁴⁹Neurology, Bayhealth Medical Center, Dover, Delaware, USA
- ¹⁵⁰Neurology, Saiseikai Fukuoka General Hospital, Fukuoka, Japan
- ¹⁵¹Division of Stroke, Department of Internal Medicine, Osaka Rosai Hospital, Sakai, Osaka, Japan
- ¹⁵²Neurology Division, Department of Medicine, King Saud University, Riyadh, Riyadh Province, Saudi Arabia
- ¹⁵³Neurology, Mount Sinai Health System, New York, New York, USA
- ¹⁵⁴Neurology, Clinical Neurosciences and Hotchkiss Brain Institute, University of Calgary, Calgary, Alberta, Canada
- ¹⁵⁵Neurology, Affiliated Hangzhou First People's Hospital, Zhejiang University School of Medicine, Hangzhou, Zhejiang, China
- ¹⁵⁶Neurology, The Affiliated Hospital of Southwest Medical University, Luzhou, Sichuan, China
- ¹⁵⁷Neurology, Yijishan Hospital of Wannan Medical College, Wuhu, Anhui, China
- ¹⁵⁸The University of Toledo, Toledo, Ohio, USA
- ¹⁵⁹Neuroscience, WellStar Health System, Marietta, Georgia, USA
- ¹⁶⁰Neuroradiologie Interventionelle, Centre Hospitalier de l'Université de Montréal, Montreal, Quebec, Canada

Twitter Thanh N Nguyen @NguyenThanhMD, Diogo C Haussen @DiogoHaussen, Ossama Y Mansour @Ossama_Mansour, Mohamad Abdalkader @AbdalkaderMD, Pedro Lylyk @eneri_neuro, Mahmoud Mohammed @MahmoudNeuro, Alhamza R Al-Bayati @AIAIBayati1, Saima Ahmad @SaimaAh46545828, Rodrigo Rivera @neurofox, Huynh Le Vu @DrLe2287, Viet Quy Nguyen @VietquyNguyen, Romain Bourcier @bourcierromain1, Malveeka Sharma @Mali27043317, Don Frei @donfreiMD, Pascal Jabbour @PascalJabbourMD, Nabeel Herial @NabeelHerial, Fawaz Al-Mufti @almuftifawaz, Dheeraj Gandhi @dgandhimd, Charles Matouk @MatoukCharles, Michael Chen @dr_mchen, Vitor Mendes Pereira @VitorMendesPer1, Patrick Nicholson @paddy Nicholson, Pedro SC Magalhães @Neurorradio, Raghid Kikano @raghidkikano, Santiago Ortega-Gutierrez @CerebrovascLab, Amal Abou-Hamden @AANeurosurgeon, Adrienne Weeks @Operatingheels, Elena A Cora @eacor, Simon Nagel @NagelSimon, Hosam Al-Jehani @HosamJehani, Sunil A Sheth @SunilAShethMD, James E Siegler @JimSiegler, Ajit S Puri @AjitSPuri1, Gianmarco Bernava @GianmarcoBerna5,

Daniel G Abud @neuroabud, Octavio M Pontes-Neto @opontesnetoMD, Eytan Raz @eytanraz, Shadi Yaghi @ShadiYaghi2, Brijesh P Mehta @NeuroINX, Steve M Cordina @SteveCordina, Juan F Arenillas @ArenillasJF, Mario Martinez-Galdamez @DoctorGaldamez, Jordi Blasco @jordiblasco, Teddy Y Wu @Teddyyhwu, Marios Psychogios @MPeyT1, Roberta Novakovic @Robin_Novakovic, Michael Kelly @michaelkelly, Hugh Stephen Winters @stephen_winters, Mohamed Teleb @italolinfante, David S Liebeskind @dliebesk, Viktor Szeder @drviktorszeder, Hesham E Masoud @HMasoud_, Brendan Steinfurt @brendan_dr, Alice Ma @alicensomalice, Ameer E Hassan @AmeerEHassan, Maxim Mokin @MokinMax, Alex Chebl @AlexChebl, Odysseas Kargiotis @OKargiotis, Dorothea Altschul @DrAltschul, Anirudh Kulkarni @anirudhvk, Pablo M Lavados @pablolavados, Veronica V Olavarria @volavarria, Gisele Sampaio Silva @GiseleSampaioS, Artem Kaliev @artemka_crh, Adel Alhazzani @AdelALHAZZANI, David Y Chung @chungmdphd, Stephan A Mayer @stephanamayer, Johanna T Fifi @johannatfifi, Michael D Hill @mihill68, Tudor G Jovin @TudorGJovin and Osama O Zaidat @oozaidat

Acknowledgements The authors thank Judith Clark, RN, Boston Medical Center; Matt Metzinger, MBA, CPHQ; Kamini Patel, RN, MSN, MBA, CPHQ, Jefferson; Janis Ginnane, RN, Emory University Hospital.

Contributors TNN and RGN conceived the project. They wrote the first draft of the paper with subsequent input from all coauthors. All coauthors played a major role in data acquisition and revision of the manuscript. MMQ was the lead statistician for this study and performed the analysis. MA prepared the global maps in the supplement.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests TNN: PI CLEAR study (Medtronic). DCH: Stryker, Vesalio, Cerenovus consultant. AEH: consultant and speaker for Medtronic, Stryker, Microvention, Penumbra, Balt, Scientia, Genentech and GE Healthcare. PJ: Medtronic, Microvention, Balt, Cerenovus consultant. SO-G: Medtronic, Stryker consultant. DSL: Cerenovus, Genentech, Stryker, Medtronic consultant. TGJ: advisor/investor for Anaconda, Route92, FreeOx, and Blockade Medical; Medtronic grants, DAWN, AURORA PI (Stryker). WJM: consultant: Rebound Therapeutics, Viseon Imperative Care, Q'Apel, Stryker, Stream Biomedical, Spartan Micro; Investor: Cerebrotech, Endostream, Q'Apel, Viseon, Rebound, and Spartan Micro. RGN: Stryker; Cerenovus/Neuravi; Anaconda, Cerebrotech, Ceretrieve, Vesalio (Advisory Board); Imperative Care.

Patient consent for publication Not required.

Ethics approval The institutional review boards (IRBs) from the coordinating sites determined that because the investigators did not have access to protected health information nor any private identifiable information, the study did not meet the definition of human subject research and therefore no informed consent or IRB oversight was required.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement All data relevant to the study are included in the article or uploaded as supplementary information. Anonymised data are available upon reasonable request from the corresponding author.

Open access This is an open access article distributed in accordance with the Creative Commons Attribution Non Commercial (CC BY-NC 4.0) license, which permits others to distribute, remix, adapt, build upon this work non-commercially, and license their derivative works on different terms, provided the original work is properly cited, appropriate credit is given, any changes made indicated, and the use is non-commercial. See: <http://creativecommons.org/licenses/by-nc/4.0/>.

ORCID iDs

Thanh N Nguyen <http://orcid.org/0000-0002-2810-1685>
 Mohamad Abdalkader <http://orcid.org/0000-0002-9528-301X>
 Laura Mechtouff <http://orcid.org/0000-0001-9165-5763>
 Pascal Jabbour <http://orcid.org/0000-0002-8965-2413>
 Teddy Y Wu <http://orcid.org/0000-0003-1845-1769>
 Ameer E Hassan <http://orcid.org/0000-0002-7148-7616>

REFERENCES

- Emanuel EJ, Persad G, Upshur R, *et al*. Fair allocation of scarce medical resources in the time of Covid-19. *N Engl J Med Overseas Ed* 2020;382:2049–55.
- Nguyen TN, Jadhav AP, Dasenbrock HH, *et al*. Subarachnoid hemorrhage guidance in the era of the COVID-19 pandemic - An

- opinion to mitigate exposure and conserve personal protective equipment. *J Stroke Cerebrovasc Dis* 2020;29:105010.
- 3 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;51:1896–901.
 - 4 Nogueira RG, Qureshi M, Abdalkader M. Global impact of COVID-19 on stroke care and intravenous thrombolysis. *American Academy of Neurology*; April 17-22, 2021.
 - 5 Alonso de Leciana M, Castellanos M, Ayo-Martín Óscar, *et al*. Stroke care during the COVID-19 outbreak in Spain: the experience of Spanish stroke units. *Stroke Vasc Neurol* 2020. doi:10.1136/svn-2020-000678. [Epub ahead of print: 04 Dec 2020].
 - 6 Ortega-Gutierrez S, Farooqui M, Zha A, *et al*. Decline in mild stroke presentations and intravenous thrombolysis during the COVID-19 pandemic: the Society of vascular and Interventional Neurology multicenter collaboration. *Clin Neurol Neurosurg* 2020;201:106436.
 - 7 Hajdu SD, Pittet V, Puccinelli F, *et al*. Acute stroke management during the COVID-19 pandemic: does confinement impact eligibility for endovascular therapy? *Stroke* 2020;51:2593–6.
 - 8 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;51:2012–7.
 - 9 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;27:1783–7.
 - 10 Seiffert M, Brunner FJ, Remmel M, *et al*. Temporal trends in the presentation of cardiovascular and cerebrovascular emergencies during the COVID-19 pandemic in Germany: an analysis of health insurance claims. *Clin Res Cardiol* 2020;109:1540–8.
 - 11 Zhao J, Li H, Kung D, *et al*. Impact of the COVID-19 epidemic on stroke care and potential solutions. *Stroke* 2020;51:1996–2001.
 - 12 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;51:2315–21.
 - 13 Siegler JE, Heslin ME, Thau L, *et al*. Falling stroke rates during COVID-19 pandemic at a comprehensive stroke center. *J Stroke Cerebrovasc Dis* 2020;29:104953.
 - 14 Hsiao J, Sayles E, Antzoulatos E, *et al*. Effect of COVID-19 on emergent stroke care: a regional experience. *Stroke* 2020;51:e2111–4.
 - 15 Nogueira R, Abdalkader M, Qureshi MM, *et al*. Global impact of the COVID-19 pandemic on stroke hospitalizations and mechanical thrombectomy volumes. *Int J Stroke* 2021:174749302199165.
 - 16 Bernat AL, Giammattei L, Abbritti R, *et al*. Impact of COVID-19 pandemic on subarachnoid hemorrhage. *J Neurosurg Sci* 2020;64:409–10.
 - 17 Diestro JDB, Li YM, Parra-Fariñas C, *et al*. Letter to the Editor 'Aneurysmal Subarachnoid Hemorrhage: Collateral Damage of COVID?'. *World Neurosurg* 2020;139:744–5.
 - 18 Hecht N, Wessels L, Werft F-O, *et al*. Need for ensuring care for neuro-emergencies-lessons learned from the COVID-19 pandemic. *Acta Neurochir* 2020;162:1795–801.
 - 19 von Elm E, Altman DG, Egger M, *et al*. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. *Ann Intern Med* 2007;147:573–7.
 - 20 Qureshi AI, Agunbiade S, Huang W, *et al*. Changes in neuroendovascular procedural volume during the COVID-19 pandemic: an international multicenter study. *J Neuroimaging* 2021;31:171–9.
 - 21 De Filippo O, D'Ascenzo F, Angelini F, *et al*. Reduced rate of hospital admissions for ACS during Covid-19 outbreak in northern Italy. *N Engl J Med* 2020;383:88–9.
 - 22 Ishihara H, Kunitsugu I, Nomura S, *et al*. Seasonal variation in the incidence of aneurysmal subarachnoid hemorrhage associated with age and gender: 20-year results from the Yamaguchi cerebral aneurysm registry. *Neuroepidemiology* 2013;41:7–12.
 - 23 Abdalkader M, Sathya A, Malek AM, *et al*. Roadmap for Resuming elective neuroendovascular procedures following the first COVID-19 surge. *J Stroke Cerebrovasc Dis* 2020;29:105177.
 - 24 Eskey CJ, Meyers PM, Nguyen TN, *et al*. Indications for the performance of intracranial endovascular Neurointerventional procedures: a scientific statement from the American heart association. *Circulation* 2018;137:e661–89.