Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Aneurysmal Subarachnoid Hemorrhage in Patients with Coronavirus Disease 2019 (COVID-19): A Case Series

William S. Dodd[1], Pascal M. Jabbour[3], Ahmad Sweid[3], Stavropoula Tjoumakaris[3], Michael R. Gooch[3], Fadi Al Saiegh[3], David M. Hasan[4], Robert M. Starke[5], Peter T. Kan[6], Adam J. Polifka[1], Dimitri Laurent[1], Katharina M. Busl[1,2], Ritam Ghosh[3], Brian L. Hoh[1], Nohra Chalouhi[1]

OBJECTIVE: **The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) pandemic is a pressing public health issue. Although most cases do not result in severe illness requiring hospitalization, there is increasing evidence that SARS-CoV-2–induced inflammation can exacerbate pre-existing diseases. We sought to describe the characteristics of patients with aneurysmal subarachnoid hemorrhage who were actively or very recently infected with SARS-CoV-2.**

METHODS: **We reviewed subarachnoid hemorrhage cases of patients who also were positive for SARS-CoV-2 at 5 high-volume cerebrovascular centers in the United States from March 2020 to January 2021. Cases of aneurysmal subarachnoid hemorrhage were analyzed.**

RESULTS: **A total of 10 patients were identified, consisting of 5 women (50%) and 5 men (50%). Median age was 38.5 years. Four of the 10 patients (40%) were asymptomatic with respect to SARS-CoV-2–related symptoms, 3 patients (30%) had mild-to-moderate symptoms, and 3 patients (30%) had severe coronavirus disease 2019 (COVID-19), with pneumonia and sepsis. Of the 10 cases, 4 had dissecting pseudoaneurysms (40%), 3 in the posterior circulation and 1 in the anterior circulation. Among 6 saccular/blister aneurysms, 4 (67%) were ≤4 mm in largest diameter.**

CONCLUSIONS: **Our experience with aneurysmal subarachnoid hemorrhage in patients positive for COVID-19 reveals a possibly distinct pattern compared with traditional aneurysmal subarachnoid hemorrhage, namely a high frequency of small aneurysms, dissecting pseudoaneurysms, and young patients.**

INTRODUCTION

Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), named due to its ~80% genetic similarity with the original SARS coronavirus,[1] is a novel betacoronavirus that initiated the coronavirus disease 2019 (COVID-19) pandemic. Like other coronaviruses, SARS-CoV2 has been shown to be able to invade the central nervous system via various routes, possesses neurotropism, and is neurovirulent.[2] There have been more than 175 million SARS-CoV-2/COVID-19 infections to date,[3] with outcomes ranging from asymptomatic infection to multiorgan failure and death. The spectrum of disease severity following SARS-CoV-2 infection is a function of host immune response. Ineffective immune response can lead to exacerbated stimulation of innate immune cells, maladaptive inflammation, and development of the so-called "cytokine storm."[4] What remains unclear, however, is the full extent to which SARS-CoV-2 infection affects extrathoracic organs and the interactions between COVID-19–induced inflammation and preexisting comorbidities. Central nervous system complications have been reported in as many as 38% of patients with varying degrees of severity.[5] There are accumulating reports of increased cerebrovascular injury[6] and

Key words
- Cerebral aneurysm
- COVID-19
- SARS-CoV-2
- Stroke
- Subarachnoid hemorrhage

Abbreviations and Acronyms
(a)SAH: (Aneurysmal) subarachnoid hemorrhage
COVID-19: Coronavirus disease 2019
mRS: modified Rankin Scale
SARS-CoV-2: Severe acute respiratory syndrome-coronavirus-2

From the Departments of [1]Neurosurgery and [2]Neurology, College of Medicine, University of Florida, Gainesville, Florida; [3]Department of Neurological Surgery, Sidney Kimmel Medical College, Thomas Jefferson University, Philadelphia, Pennsylvania; [4]Department of Neurosurgery, Carver College of Medicine, University of Iowa, Iowa City, Iowa; [5]Department of Neurological Surgery, Miller School of Medicine, University of Miami, Miami, Florida; and [6]Department of Neurosurgery, University of Texas Medical Branch, Galveston, Texas, USA

To whom correspondence should be addressed: Nohra Chalouhi, M.D. [E-mail: nohra.elchalouhi@neurosurgery.ufl.edu]

Citation: World Neurosurg. (2021) 153:e259-e264. https://doi.org/10.1016/j.wneu.2021.06.092

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

Available online: www.sciencedirect.com

ischemic stroke[7] in patients with COVID-19, but reports on subarachnoid hemorrhage (SAH) and cerebral aneurysm rupture are limited to few case reports with largely nonaneurysmal SAH, and only 1reported aneurysmal subarachnoid hemorrhage (aSAH) to date.[8]

The prevalence of cerebral aneurysms in the adult population is estimated to be between 2% and 4%.[9,10] Most cerebral aneurysms are saccular in morphology, whereas fusiform, blister, and dissecting pseudoaneurysms are rare.[11-13] The risk of an aneurysm rupturing is heavily influenced by risk factors like age, sex, smoking status, hypertension, and aneurysm size, morphology, and location, varying from 0% to 50% risk of rupture over a 5-year interval.[13-15] Mechanistically, aneurysm formation is driven by weakening of the vascular internal elastic lamina secondary to hemodynamic stress and inflammation.[16] Progressive inflammation, mediated predominantly by monocytes/macrophages,[17,18] can then cause vascular smooth muscle cell apoptosis and vessel wall thinning, leading to aneurysm rupture and SAH.[19,20]

We are observing across several institutions instances of aneurysm ruptures occurring in patients testing positive for COVID-19. The purpose of this study is to describe and analyze the characteristics of these patients.

METHODS

Patient Data

Data were collected retrospectively from patients treated at 5 high-volume cerebrovascular centers from March 2020 to January 2021 with a diagnosis of spontaneous SAH. Patients with a confirmed aneurysmal rupture and a diagnosis of SARS-CoV-2 infection (made based on reverse transcriptase-quantitative polymerase chain reaction testing of a nasopharyngeal swab sample from each patient during hospital admission and up to 28 days before admission following standard protocols[21,22]) were included in the final analysis. The following data were collected from each patient's record: age, sex, aneurysm type, aneurysm location, Hunt and Hess classification, presenting symptoms, COVID-19 symptoms, aneurysm treatment, length of stay, modified Rankin scale (mRS) at discharge, history of hypertension, history of diabetes, history of cerebral aneurysms, history of chronic heart disease, and history of chronic lung disease. To preserve patient anonymity and in compliance with institutional review board regulations, we do not present the full data for individual cases and instead report the aggregated data or individual deidentified data points.

RESULTS

Patient Characteristics and Presentation

There were 10 patients. Patient characteristics are summarized in Table 1. There were 5 women (50%) and 5 men (50%). The median age was 38.5 years old (interquartile range: 36.5–45 years, range: 29–57 years). All 10 patients tested positive for COVID-19 when the SAH occurred. Four of the 10 patients (40%) were asymptomatic with respect to COVID-19–related symptoms, testing positive for the virus upon admission for aSAH. Three patients (30%) had mild-to-moderate symptoms, including cough, sore throat, and/or low-grade fever. The remaining 3 patients (30%) had severe cases; all 3 were diagnosed with pneumonia and sepsis, and 1 patient also suffered acute kidney injury. One patient had recovered from COVID-19 pneumonia and sepsis before developing aSAH 2 weeks later. The patient was still positive for COVID-19 at the time of the hemorrhage. No patient had a documented history of chronic lung disease or chronic heart disease. Interestingly, 1 patient with a dissecting pseudoaneurysm of the right vertebral artery had a magnetic resonance imaging study of the brain from 2005 that showed no evidence of aneurysm at that time (Figure 1).

Hunt and Hess grades were as follows: grade II, 3 patients (30%); grade III, 3 patients (30%); grade IV, 3 patients (30%); grade V, 1 patient (10%) (Table 1).

Table 1. Patient Characteristics and Presentation

Characteristic	*N*	%
Sex		
Female	5	50
Male	5	50
Age, years		
<30	1	10
30–40	5	50
40–50	2	20
>50	2	20
COVID-19 severity		
Asymptomatic	4	40
Mild	2	20
Moderate	1	10
Severe	3	30
Comorbidities		
Chronic lung disease	0	0
Chronic heart disease	0	0
Hypertension	1	10
Diabetes	0	0
Hunt and Hess grade		
1	0	0
2	3	30
3	3	30
4	3	30
5	1	10
Outcome		
Good recovery (mRS 0–2)	7	70
Moderate Disability (mRS 3–4)	1	10
Severe disability or death (mRS 5–6)	2	20

COVID-19, coronavirus disease 2019; mRS, modified Rankin Scale score.

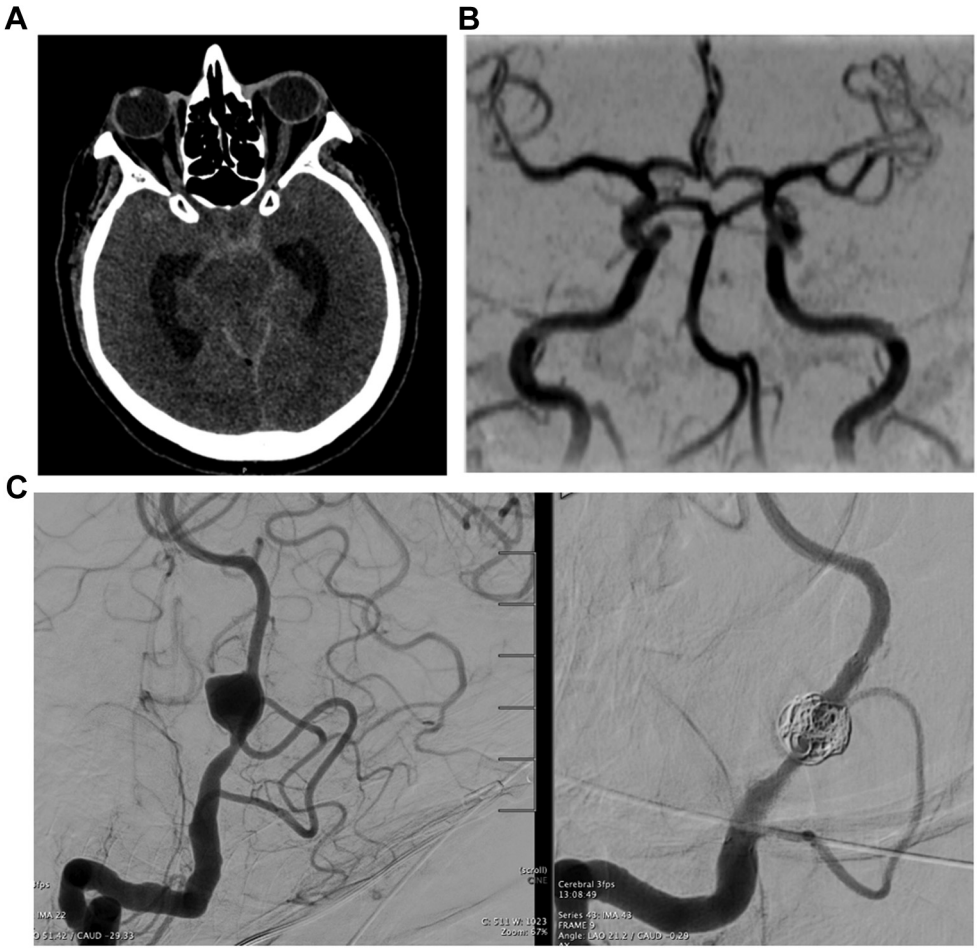

Figure 1. (**A**) A middle-aged patient who had just recovered from severe coronavirus disease 2019 pneumonia developed the worst headache of their life and rapidly became obtunded. Computed tomography of the head showed subarachnoid hemorrhage (SAH) concentrated in the prepontine and premedullary cisterns. A right frontal ventriculostomy was placed. (**B**) Magnetic resonance angiography of the head performed 15 years before the SAH showing no aneurysms in the right vertebral artery. (**C**) Right vertebral artery angiography showing a dissecting aneurysm of the V4 segment of the right vertebral artery before and after successful treatment with Flow-Redirection Endoluminal Device (FRED; MicroVention, Aliso Viejo, California, USA)-assisted coiling.

Aneurysm Features and Treatment

Of the 10 cases reviewed, there were 5 saccular aneurysms (50%), 1 blister-type aneurysm (10%), and 4 dissecting pseudoaneurysms (40%). Of note, one patient died before we obtained a cerebral angiogram, but imaging was highly suspicious for a dissecting pseudoaneurysm of the left posterior cerebral artery. The saccular aneurysms were 3, 3, 4, 15, and 19 mm in diameter whereas the blister aneurysm was only 1.5 mm. The dissecting pseudoaneurysms were 5, 6, 15, and 21 mm in diameter.

Aneurysm location, type, and treatment are summarized in Table 2. Seven aneurysms (70%) occurred in the anterior circulation (3 in the anterior communicating artery, 1 in the middle cerebral artery, 1 in the posterior communicating segment, 1 in the ophthalmic segment, and 1 anterior choroidal aneurysm) and 3 (30%) occurred in the vertebrobasilar system (all 3 were dissecting pseudoaneurysms; 1 in the posterior cerebral artery, 1 in the posterior inferior cerebellar artery (Figure 2), and 1 in the vertebral artery). Three aneurysms were treated with endovascular coiling (Figure 3), 3 with microsurgical clipping, and 3 with flow diversion. One patient who presented with a poor neurologic examination and did not improve after a decompressive hemicraniectomy died without undergoing aneurysm treatment.

Patient Outcomes

One patient developed cerebral vasospasm and delayed cerebral ischemia and underwent infusion of intra-arterial verapamil. Another patient underwent evacuation of a postoperative

Table 2. Aneurysm Features and Treatment

Case	Aneurysm Location	Aneurysm Morphology	Aneurysm Size, mm	Treatment
1	Anterior communicating artery	Saccular	3	Coiling
2	Anterior communicating artery	Saccular	3	Coiling
3	Left middle cerebral artery	Saccular	4	Clipping
4	Anterior choroidal artery	Blister	1.5	Flow diversion
5	Posterior communicating artery	Saccular	15	Clipping
6	Left ophthalmic artery	Saccular	19	Coiling
7	Right vertebral artery	Dissecting pseudoaneurysm	5	Flow diversion
8	Posterior inferior cerebellar artery	Dissecting pseudoaneurysm	5	Flow diversion
9	Anterior communicating artery	Dissecting pseudoaneurysm	15	Coiling
10	Posterior cerebral artery	Dissecting pseudoaneurysm	21	Expiration prior to treatment

hematoma following microsurgical clipping. Clinical outcomes at discharge were as follows: mRS 0–2 in 7 patients (70%); mRS 3 in 1 patient (10%), and mRS 6 in 2 patients (20%) (Table 1). Both patients who died presented with high-grade SAH, did not improve after several days, and eventually were transitioned to end-of-life care.

DISCUSSION

The influence of SARS-CoV-2 infection on cerebral aneurysm pathology and rupture risk is unknown. In this study, we describe the clinical characteristics of patients with aSAH who were positive for SARS-CoV-2. A prospective cohort and natural history studies demonstrate propensity for aneurysmal rupture to occur in patients older than 50 years of age.[23,24] In this case series, 8 of 10 patients (80%) were younger than 50 years of age. In contrast, in the International Subarachnoid Aneurysm Trial (ISAT), only about 40% of patients were younger than 50 years of age.[25] Likewise, in the Barrow ruptured aneurysm trial, the mean age was 53 years in the clip group and 54 years in the coil group.[24]

Saccular aneurysms are the most common culprits of aSAH (up to 90% of cases), and large size increases rupture risk.[13,26] Of the 6 cases of saccular/blister aneurysms reviewed at our institutions, there were 4 that were 4 mm in diameter or less. The expected rupture rate for saccular aneurysms <5 mm in size is exceedingly low, i.e., less than 1% over a 5-year interval.[13] While small aneurysms can rupture,[27] it is noteworthy to have such a high proportion of very small aneurysms (1.5 mm, 3 mm, 3 mm, and 4 mm) in a small series.

Our study also includes 4 dissecting pseudoaneurysms and 1 blister aneurysm, together representing 50% of the cases. Dissecting and blister aneurysms are less-common causes of aSAH than saccular aneurysms.[11] Precise estimates are difficult, but most studies report dissecting pseudoaneurysms and blister aneurysms to each represent approximately only 1% of cerebral aneurysms[28-32]; therefore, it is noteworthy to have such a high frequency of these lesions in a small case series. The pathophysiology of dissecting pseudoaneurysms differs from saccular aneurysms as it involves a defect in the internal elastic lamina followed by mural dissection and pseudoaneurysm formation. The

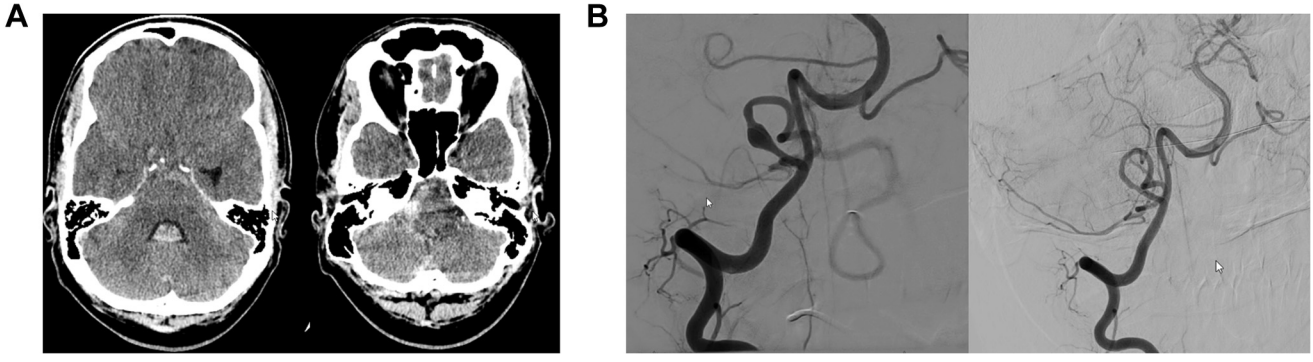

Figure 2. (**A**) A young patient with recent onset of cough presented with a severe headache and lethargy; computed tomography of the head showed subarachnoid hemorrhage and interventricular hemorrhage. Patient tested positive for severe acute respiratory syndrome coronavirus 2 upon admission. (**B**) Right vertebral artery angiography showing a dissecting pseudoaneurysm of the posterior inferior cerebellar artery. A Pipeline embolization device was deployed to treat the lesion. Six-month follow-up angiography showed complete aneurysm resolution.

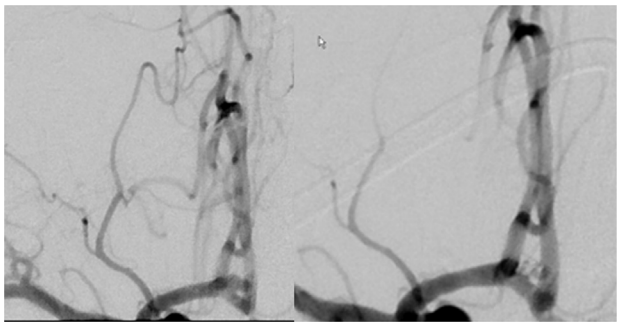

Figure 3. A young patient presented with a severe headache and lethargy/confusion. The patient was also experiencing a sore throat, cough, and a low-grade fever and tested positive for severe acute respiratory syndrome coronavirus 2 upon admission. Right internal carotid artery injection showing a 3-mm anterior communicating artery aneurysm, which was successfully coiled.

potential association seen in this series between COVID-19 and dissecting pseudoaneurysms could be interesting but it remains to be seen how COVID-19 could contribute to intracranial artery dissection and pseudoaneurysm formation.

The influence of the COVID-19 pandemic on access and delivery of healthcare is a potentially influential variable in our study. There was a decrease in admissions for SAH and ruptured aneurysm embolization procedures during the pandemic,[33] consistent with the notion that pressures on the health care system and public avoidance behaviors caused a decline in healthcare access.[34] Further, we did not collect patient history of connective tissue disorders or recent head trauma, both of which can cause dissecting aneurysms.[35,36] These factors could potentially influence the number or characteristics of the patients included in this series. In contrast, it is reassuring that the outcomes in our cases do not seem to differ from what is expected with aSAH. Three of 10 patients had an mRS of >2 at discharge, which is consistent with existing literature.[24]

The current study is not designed to establish a causality between COVD-19 and cerebral aneurysm rupture; instead, it is meant to describe and analyze the characteristics of ruptured aneurysms in patients with COVID-19. Given the high incidence of small aneurysm ruptures in young patients in this series, one could speculate that—in a subset of patients—the inflammatory response accompanying COVID-19 may cause the premature rupture of preexisting saccular cerebral aneurysms that would have otherwise ruptured at a later age when they have grown larger in size. We suggest that any relationship between SARS-CoV-2 infection and cerebral aneurysm rupture could possibly involve macrophage-mediated production of interleukin-1β, interleukin-6, and tumor necrosis factor-α. Macrophages are actually highly implicated in both aneurysmal rupture and COVID-19—related inflammations.[17,37,38] This remains, however, purely speculative and warrants additional investigation. A larger sample of patients with aSAH and measurement of inflammatory mediators would be especially valuable in defining the association between SARS-CoV-2 infection and aSAH.

CONCLUSIONS

Over 1-year into the COVID-19 pandemic, the global community is constantly discovering sequelae of SARS-CoV-2 infection. In this case series, we report 10 aSAH cases that occurred in patients positive for SARS-CoV-2. These cases are the first case series of this specific phenomenon and they raise questions on a possible interaction between SARS-CoV-2 infection and cerebral aneurysm rupture. The atypical features, namely small size, presence of dissection, and young age, deserve further study.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

William S. Dodd: Data curation, Formal analysis, Writing — original draft. **Pascal M. Jabbour:** Conceptualization, Data curation, Methodology, Project administration, Writing — review & editing. **Ahmad Sweid:** Data curation, Formal analysis, Writing — review & editing. **Stavropoula Tjoumakaris:** Data curation, Formal analysis, Writing — review & editing. **Michael R. Gooch:** Data curation, Formal analysis, Writing — review & editing. **Fadi Al Saiegh:** Data curation, Formal analysis, Writing — review & editing. **David M. Hasan:** Conceptualization, Data curation, Methodology, Project administration, Writing — review & editing. **Robert M. Starke:** Conceptualization, Data curation, Methodology, Project administration, Writing — review & editing. **Peter T. Kan:** Conceptualization, Data curation, Methodology, Project administration, Writing — review & editing. **Adam J. Polifka:** Conceptualization, Data curation, Methodology, Project administration, Writing — review & editing. **Dimitri Laurent:** Data curation, Formal analysis, Writing — original draft. **Katharina M. Busl:** Conceptualization, Data curation, Methodology, Project administration, Writing — review & editing. **Ritam Ghosh:** Data curation, Formal analysis, Writing — review & editing. **Brian L. Hoh:** Conceptualization, Data curation, Methodology, Project administration, Writing — review & editing. **Nohra Chalouhi:** Conceptualization, Data curation, Methodology, Project administration, Writing — review & editing.

REFERENCES

1. Lai CC, Shih TP, Ko WC, Tang HJ, Hsueh PR. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and coronavirus disease-2019 (COVID-19): the epidemic and the challenges. *Int J Antimicrob Agents*. 2020;55:105924.
2. Lima M, Siokas V, Aloizou AM, et al. Unraveling the possible routes of SARS-COV-2 invasion into the central nervous system. *Curr Treat Options Neurol*. 2020;22:37.
3. Dong E, Du H, Gardner L. An interactive web-based dashboard to track COVID-19 in real time. *Lancet Infect Dis*. 2020;20:533-534.
4. Jose RJ, Manuel A. COVID-19 cytokine storm: the interplay between inflammation and coagulation. *Lancet Respir Med*. 2020;8:e46-e47.
5. Yu H, Sun T, Feng J. Complications and pathophysiology of COVID-19 in the nervous system. *Front Neurol*. 2020;11:573421.
6. Lee M-H, Perl DP, Nair G, et al. Microvascular injury in the brains of patients with Covid-19. *N Engl J Med*. 2021;384:481-483.
7. Hess DC, Eldahshan W, Rutkowski E. COVID-19-related stroke. *Transl Stroke Res*. 2020;11:322-325.

8. Cezar-Junior AB, Faquini IV, Silva JLJ, et al. Subarachnoid hemorrhage and COVID-19. *Medicine (Baltimore)*. 2020;99:e23862.

9. Etminan N, Rinkel GJ. Unruptured intracranial aneurysms: development, rupture and preventive management. *Nat Rev Neurol*. 2016;12:699-713.

10. Wardlaw JM, White PM. The detection and management of unruptured intracranial aneurysms. *Brain*. 2000;123:205-221.

11. Krings T, Mandell DM, Kiehl TR, et al. Intracranial aneurysms: from vessel wall pathology to therapeutic approach. *Nat Rev Neurol*. 2011;7:547-559.

12. Park SH, Yim M Bin, Lee CY, Kim E, Son EI. Intracranial fusiform aneurysms: it's pathogenesis, clinical characteristics and managements. *J Korean Neurosurg Soc*. 2008;44:116-123.

13. Brown RD, Broderick JP. Unruptured intracranial aneurysms: epidemiology, natural history, management options, and familial screening. *Lancet Neurol*. 2014;13:393-404.

14. Juvela S, Hillbom M, Numminen H, Koskinen P. Cigarette smoking and alcohol consumption as risk factors for aneurysmal subarachnoid hemorrhage. *Stroke*. 1993;24:639-646.

15. Knekt P, Reunanen A, Aho K, et al. Risk factors for subarachnoid hemorrhage in a longitudinal population study. *J Clin Epidemiol*. 1991;44:933-939.

16. Signorelli F, Sela S, Gesualdo L, et al. Hemodynamic stress, inflammation, and intracranial aneurysm development and rupture: a systematic review. *World Neurosurg*. 2018;115:234-244.

17. Shimizu K, Kushamae M, Mizutani T, Aoki T. Intracranial aneurysm as a macrophage-mediated inflammatory disease. *Neurol Med Chir (Tokyo)*. 2019;59:126-132.

18. Kanematsu Y, Kanematsu M, Kurihara C, et al. Critical roles of macrophages in the formation of intracranial aneurysm. *Stroke*. 2011;42:173-178.

19. Tulamo R, Frosen J, Hernesniemi J, Niemela M. Inflammatory changes in the aneurysm wall: a review. *J Neurointerv Surg*. 2010;2:120-130.

20. Chalouhi N, Ali MS, Jabbour PM, et al. Biology of intracranial aneurysms: role of inflammation. *J Cereb Blood Flow Metab*. 2012;32:1659-1676.

21. Wiersinga WJ, Rhodes A, Cheng AC, Peacock SJ, Prescott HC. Pathophysiology, transmission, diagnosis, and treatment of coronavirus disease 2019 (COVID-19): a review. *JAMA*. 2020;324:782-793.

22. Centers for Disease Control and Prevention. Real-time RT-PCR Primers and Probes for COVID-19. Available at: https://www.cdc.gov/coronavirus/2019-ncov/lab/rt-pcr-panel-primer-probes.html. Accessed June 17, 2021.

23. UCAS Japan Investigators. The natural course of unruptured cerebral aneurysms in a Japanese cohort. *N Engl J Med*. 2012;366:2474-2482.

24. McDougall CG, Spetzler RF, Zabramski JM, et al. The barrow ruptured aneurysm trial: clinical article. *J Neurosurg*. 2012;116:135-144.

25. Molyneux AJ, Kerr RS, Yu LM, et al. International Subarachnoid Aneurysm Trial (ISAT) of neurosurgical clipping versus endovascular coiling in 2143 patients with ruptured intracranial aneurysms: a randomised comparison of effects on survival, dependency, seizures, rebleeding, subgroups, and aneurysm occlusion. *Lancet*. 2005;366:809-817.

26. D'Souza S. Aneurysmal subarachnoid hemorrhage. *J Neurosurg Anesthesiol*. 2015;27:222-240.

27. Zanaty M, Daou B, Chalouhi N, Starke RM, Jabbour P, Hasan D. Evidence that a subset of aneurysms less than 7 mm warrant treatment. *J Am Heart Assoc*. 2016;5.

28. Zheng Y, Lu Z, Shen J, Xu F. Intracranial pseudoaneurysms: evaluation and management. *Front Neurol*. 2020;11:582.

29. El Mekabaty A, Toth G, Gandhi D, Coon A, Hui FK. Dissecting pseudoaneurysms and blister aneurysms. In: Spiotta AM, Turner RD, Chaudry MI, Turk AS, eds. *Management of Cerebrovascular Disorders*. Cham: Springer International Publishing; 2019:255-272.

30. Meling TR, Sorteberg A, Bakke SJ, Slettebø H, Hernesniemi J, Sorteberg W. Blood blister-like aneurysms of the internal carotid artery trunk causing subarachnoid hemorrhage: treatment and outcome. *J Neurosurg*. 2008;108:662-671.

31. Lee BH, Byung MK, Moon SP, et al. Reconstructive endovascular treatment of ruptured blood blister-like aneurysms of the internal carotid artery: clinical article. *J Neurosurg*. 2009;110:431-436.

32. Daou B, Hammer C, Chalouhi N, et al. Dissecting pseudoaneurysms: predictors of symptom occurrence, enlargement, clinical outcome, and treatment. *J Neurosurg*. 2016;125:936-942.

33. Nguyen TN, Haussen DC, Qureshi MM, et al. Abstract 14: global impact of the covid-19 pandemic on subarachnoid hemorrhage. *Stroke*. 2021;52(suppl_1).

34. Hartnett KP, Kite-Powell A, DeVies J, et al. Impact of the COVID-19 pandemic on emergency department visits—United States, January 1, 2019—May 30, 2020. *MMWR Morb Mortal Wkly Rep*. 2020;69:699-704.

35. Schievink WI. Genetics of intracranial aneurysms. *Neurosurgery*. 1997;40:651-663.

36. Larson PS, Reisner A, Morassutti DJ, Abdulhadi B, Harpring JE. Traumatic intracranial aneurysms. *Neurosurg Focus*. 2000;8:1-6.

37. Merad M, Martin J. Pathological inflammation in patients with COVID-19: a key role for monocytes and macrophages. *Nat Rev Immunol*. 2020;20:355-362.

38. Liao M, Liu Y, Yuan J, et al. The landscape of lung bronchoalveolar immune cells in COVID-19 revealed by single-cell RNA sequencing [e-pub ahead of print]. *Nat Med*. https://doi.org/10.1101/2020.02.23.20026690, accessed December 17, 2020.

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

Received 13 April 2021; accepted 18 June 2021

Citation: World Neurosurg. (2021) 153:e259-e264. https://doi.org/10.1016/j.wneu.2021.06.092

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

*Available online: **www.sciencedirect.com***