Cerebrovascular Disorders (D Jamieson, Section Editor)

Stroke Treatment in the Era of COVID-19: a Review

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Abstract

Purpose of Review To describe a comprehensive review of the epidemiology, pathophysiology, and treatment of stroke in the era of COVID-19.

Recent Findings COVID-19 is associated with myriad neurological disorders, including cerebrovascular disease. While ischemic stroke is the most common, COVID-19 is associated with an increased risk of intracranial hemorrhage, arterial dissection, posterior reversible encephalopathy syndrome, and cerebral venous sinus thrombosis. In this review, we discuss the epidemiology, pathophysiology, and treatment of stroke due to COVID-19. In addition, we describe how COVID-19 has changed the landscape of stroke systems of care and the effect this has had on patients with cerebrovascular disease.

Summary While COVID-19 is associated with a heightened risk of stroke, the pandemic has led to advances in stroke systems of care that may reduce the long-term burden of stroke.
Introduction

As of July 2021, the COVID-19 pandemic caused by SARS-CoV2 has infected 196 million people and has led to over 4,200,000 deaths worldwide. A growing body of evidence has found an association between COVID-19 and a variety of neurological disorders, including cerebrovascular disease. The shift of hospitals' resources and health care staff towards the

COVID-19 pandemic has led to alterations in regular medical care, particularly for stroke [1]. In this article, we review the epidemiology, pathophysiology, and treatment of stroke in the era of COVID-19. In addition, we describe how COVID-19 has changed systems of stroke care and the effect this has had on patients with cerebrovascular disease.

Stroke Incidence Among Patients With COVID-19

COVID-19 is associated with a variety of cerebrovascular complications. Multiple studies have found that patients with COVID-19 are at higher risk of stroke [2–4]. While ischemic stroke is the most common cerebrovascular manifestation, COVID-19 is also associated with intracranial hemorrhage, cervical artery dissection, posterior reversible encephalopathy syndrome (PRES), and cerebral venous thrombosis [5, 6].

In one large meta-analysis of over 60,000 patients hospitalized with COVID-19, a cerebrovascular event occurred in 1.3% of cases, the most common of which was ischemic stroke. As compared to non-infected contemporary or historic controls, patients with COVID-19 had a 3.6-fold increased risk of ischemic stroke, [7•] and similar findings have been found in other meta-analyses [8]. The risk of stroke appears to be correlated with the severity of COVID. The risk of stroke is approximately 1% among patients with mild COVID-19 symptoms, [9•] and may be as high as 5.7% among patients hospitalized in the intensive care unit with COVID-19 [9•, 10].

While respiratory illnesses in general have previously been found to be associated with a heightened risk of stroke, [11] COVID-19 appears to be associated with an even higher risk of stroke. As compared to patients with influenza, patients with COVID-19 faced a 7-fold higher risk of stroke [12•]. The particularly high risk of stroke among patients with COVID-19 may be related to the high levels of inflammation, hypercoagulability, or medical severity and systemic complications that result from COVID and place patients at heightened risk for stroke [13, 14].

One of the potential drivers for the heightened risk of stroke seen among patients with COVID-19 may be the propensity for clot formation and subsequent embolism to the brain. In support of this, studies have found an increased risk of large vessel occlusions (LVOs) among patients with COVID [13, 15, 16]. LVOs, defined as blockages of the proximal intracranial arteries in the anterior or posterior circulation, account for approximately 10 to 30% of acute ischemic strokes in the general population [17–19]. Patients with COVID-19 appear to be at heightened risk of having a LVO [17, 20–22]. In addition, patients with COVID-19 who have LVOs are younger than patients without COVID-19 with LVOs [28]. The difference may be that younger patients with COVID-19 have heightened levels of inflammation and hypercoagulability whereas patients without COVID-19 who have LVOs often have
risk factors associating with aging like atrial fibrillation or system atherosclerosis [23].

Little data exist regarding the impact of pregnancy and the risk of stroke in patients with COVID-19. Case reports have shown variable outcomes in pregnant patients with COVID-19 and strokes [24]. A single case report described cerebral vasculitis (or more likely reversible cerebral vasoconstriction syndrome) in a pregnant patient with COVID-19 who was found to have subarachnoid hemorrhage with complete resolution of symptoms [25].

Mechanism and Pathophysiology of Ischemic Stroke in COVID-19

The mechanism of stroke in patients with COVID-19 is likely multifactorial (Fig. 1). COVID-19 predisposes to a multitude of systemic complications including atrial fibrillation, myocardial infarction, myocarditis, and infective endocarditis, which are all well-associated with stroke [26, 27]. In addition, COVID-19 increases the propensity for direct viral-induced endothelium damage and inflammation, [28] and hypercoagulability from cytokine storm [4], both of which predispose to thrombus formation and stroke [29, 30]. The hypercoagulable state increases both the risk of venous thromboembolism leading to deep venous thrombosis (DVT) and pulmonary embolism (PE) which can travel to the brain and cause stroke through paradoxical embolism, [31•] and potentially also increases the risk of in situ arterial thrombosis [32, 33]. In a study of 3,334 hospitalized patients with COVID-19, thrombosis occurred in 16%, of which 6.2% were venous (DVT/PE) and 11.1% were arterial [34•]. In addition, an Italian study found that despite the use of prophylactic anticoagulation, the rate of venous and arterial thromboses in patients hospitalized with COVID-19 was as high as 8% [5].

The pathogenesis of hypercoagulability in COVID-19 patients involves all three components of the Virchow’s triad, including endothelial injury, hypercoagulable state, and stasis [35]. Endothelial injury is evident both from the direct invasion of endothelial cells by SARS-CoV-2 and from increased cytokines release, such as interleukin IL-6, and various acute-phase reactants in COVID-19 that lead to endothelial injury [28, 36]. Stasis is due to immobilization in all hospitalized patients, especially those who are critically ill [35]. Finally, a hypercoagulable state is seen due to several coagulation abnormalities from elevated circulating prothrombotic factors such as von Willebrand factor (vWF), D-dimer, fibrinogen, and factor VIII [35, 37].

The increased inflammation and the release of pro-inflammatory cytokines including the tissue factor (TF) leads to coagulation activation and thrombin generation, causing both arterial and venous thromboembolism, [34•, 38] leading to DVT and PE and paradoxical embolism stroke [5, 31•]. Moreover, COVID-19 patients with elevated levels of D-dimer are at increased risk of venous and arterial events and poor prognosis [34•]. A recent study has shown that D-dimer was the only biomarker independently associated with prevalent stroke, with an 8-fold increase in COVID-19 patients [39].
Notably, there appears to be a heightened proportion of cryptogenic stroke among patients with stroke due to COVID-19 [40]. In a meta-analysis of 60,000 patients hospitalized with COVID-19, as compared to non-infected contemporary or historic controls, patients with COVID-19 had a 4-fold increased risk of cryptogenic ischemic stroke (Fig. 2) [7•]. These findings have been replicated in other studies [41]. Although a proportion of these patients may have cryptogenic stroke due to incomplete workups or multiple stroke etiologies, many of these strokes appear to embolic stroke of undetermined source (ESUS) and are thought to occur due to a state of hypercoagulability without any obvious high-risk source of cardiac embolism [42]. COVID-19 is also associated with atrial and ventricular cardiopathy, arrhythmias, and endothelial activation which may predispose to stroke without satisfying the criteria for cardioembolism [43–45]. These cryptogenic strokes are not benign, and in fact portend a poor prognosis. A large population study found that cryptogenic stroke was an independent predictor of mortality, suggesting that COVID-19-associated cryptogenic stroke may represent a state of
systemic hypercoagulability or endothelial activation that is associated with higher mortality [46].

**Mechanism and Pathophysiology of Non-ischemic Stroke in COVID-19**

COVID-19 is similarly associated with a heightened risk of non-ischemic cerebrovascular disorders. Prior studies have showed not only an increased risk of ischemic strokes, but also associations between COVID-19 and cervical artery dissection, intraparenchymal hemorrhage (IPH), cerebral venous sinus thrombosis (CVST), and posterior reversible encephalopathy syndrome (PRES) (Fig. 3).

COVID-19-related IPH is less common than ischemic strokes, but several studies have pointed to an association between COVID-19 and IPH [47–50]. IPH have been reported in about 0.5% of COVID-19 patients [51]. The proposed mechanisms of IPH in COVID-19 are related to both direct and indirect endothelial toxicity, the former via direct viral endothelial cell invasion and the latter through inflammation that leads to thrombotic events which ultimately disrupt tight junction protein complexes.
leading to blood-brain barrier compromise and IPH \cite{48, 49}. In addition, the heightened risk of IPH among patients with COVID-19 may be related to the increased use of anticoagulation. Kvernland et al. showed that 89.5% of patients with COVID-19 and non-traumatic intracerebral hemorrhage or spontaneous non-aneurysmal subarachnoid hemorrhage were on therapeutic anticoagulation at the time of their hemorrhagic stroke \cite{52}.

Posterior reversible encephalopathy syndrome (PRES) has also been identified as a complication of COVID-19 and/or its treatment \cite{53–55}. PRES may be due to direct invasion of endothelial cells by Sars-CoV-2 through surface angiotensin-converting enzyme 2 (ACE2) receptors, leading to endothelial dysfunction and to increased vascular permeability. It has been hypothesized that shifting the vascular equilibrium towards a more pro-inflammatory, pro-coagulant, and proliferative state may lead to inflammation with edema \cite{56}. PRES may also be a consequence of medical illness and/or medical therapy utilized among hospitalized COVID-19 patients \cite{57}. Renal failure, an independent predictor of PRES, is not uncommon among critically ill COVID-19 patients \cite{58}. Immunomodulatory medications commonly given to COVID-19 patients, such as tocilizumab, are also associated with increased risk for PRES \cite{59}.

Cervical artery dissection is known to be associated with respiratory illnesses either through direct viral invasion, a heightened state of inflammation, or microtrauma due to coughing \cite{11}. Few case series of dissections have also been reported in patients with COVID-19, \cite{60} and the proposed mechanisms for arterial dissection seem related to the endothelial dysfunction
resulting from cytokine storm or direct SARS-CoV-2 invasion of the vascular endothelial cells through the surface ACE2 receptors [61, 62]. The propensity for cervical artery dissection among patients with respiratory illnesses has recently been borne out, [11] and it is uncertain whether COVID-19 predisposes to a higher risk of dissection than other respiratory illnesses.

Finally, cerebral venous thrombosis (CVT) has been reported in about 0.5% of patients hospitalized with COVID-19 [51]. CVT has been described to affect especially the transverse and sigmoid sinus, with involvement of the deep venous sinus system in about one-third of the cases [63–66]. Among hospitalized patients with COVID-19, CVT is associated with elevated D-dimer and C-reactive protein (C-RP) levels. The proposed mechanism is related to the pro-coagulant state induced by the virus [65, 67].

**Prognosis in Patients With COVID-19 and Stroke**

Patients with COVID-19 appear to have more severe strokes than patients without COVID-19 [68]. A recent systematic review found that patients with COVID-19 and stroke had higher National Institutes of Health Stroke Scale (NIHSS) scores than non-infected counterparts [68, 69]. Moreover, patients with COVID-19 and stroke were younger than non-COVID-19 patients with stroke, and patients with COVID-19 and stroke had more unfavorable neurological outcomes as compared to patients with stroke without COVID [70]. Thus, COVID-19-associated stroke affects younger patients, and is associated with higher stroke severity and worse neurological outcomes. Potential explanations of this higher stroke severity may be related to the higher risk of LVOs among COVID-19 patients, [17, 22, 71] or related to the underlying medical severity of patients with COVID-19 who have stroke. Another explanation for worse neurological outcomes may be related to the decreased use of acute stroke therapies such as tPA and mechanical thrombectomy (MT) [72, 73]. In fact, patients with COVID-19 may be less likely to receive tPA and MT, [73] especially in cases of severe infection. This may be due to several factors, including delay in stroke symptom identification due to the use of medically induced coma or paralytics. In addition, patients with severe COVID-19 may be on therapeutic anticoagulation for systemic clots or may have severe medical comorbidities that may exclude them from receiving MT and tPA [52, 72–75].

Outcomes for patients with COVID-19 and stroke appear to be worse than patients without COVID-19 and stroke. Initial reports from China described a higher risk of poor outcomes associated with a history of stroke among COVID-19 patients, with increased rates of in-hospital mortality [76]. Studies from the USA showed that up to 63.6% of COVID-19-infected patients died during their hospitalization after suffering a stroke [41]. A recent study from Qureshi et al. that analyzed over 27,000 patients, showed a 2-fold increase in the risk of discharge to destination other than home or of death with occurrence of acute ischemic stroke in patients with COVID-19 [74].
The worse outcomes in patients with COVID-19 and stroke may be related to the underlying severity of medical illness, the heightened state of inflammation or hypercoagulability, or delays in the delivery of acute stroke therapies like thrombolysis or mechanical thrombectomy. A recent meta-analysis of 2955 patients who presented with stroke symptoms during the COVID-19 pandemic found that during the initial peak COVID-19 period (March 1, 2020, to July 31, 2020), patients with stroke had lower odds of receiving thrombolysis within 60 min of arrival (OR 0.61) as compared to patient who presented with stroke symptoms in the pre-COVID-19 period [77]. Despite the increased door-to-needle time, the study found no significant delay in door-to-groin time for patients who underwent MT [77]. However, a study conducted in 28 centers from North America, South America, and Europe found that during the pandemic stroke patients were more likely to undergo intubation prior to thrombectomy, leading to prolonged door-to-reperfusion time, higher in-hospital mortality, and lower likelihood of functional independence at discharge [78].

### Acute Stroke Treatment of Stroke During the COVID-19 Pandemic

#### Thromboprophylaxis

Patients with COVID-19 are at heightened risk for thrombotic complications [79]. Given the concern for a pro-coagulant state in COVID-19 patients, a randomized clinical trial evaluated the efficacy of prophylactic anticoagulation in non-critically ill patients with COVID-19 and found that therapeutic anticoagulation with heparin increased the probability of survival to hospital discharge with reduced use of cardiovascular or respiratory organ support as compared with usual-care thromboprophylaxis [80]. However, among critically ill patients with COVID-19, the INSPIRATION trial found that intermediate dose prophylactic anticoagulation was not superior to standard-dose prophylaxis in reducing the risk of acute VTE, arterial thrombosis, treatment with extracorporeal membrane oxygenation, or death [81]. In addition, recently published clinical trials have shown that prolonged therapeutic anticoagulation with 30 days of rivaroxaban in patients with COVID-19 and elevated D-dimer increased the risk of bleeding without improving outcomes compared to prophylactic anticoagulation [82]. Given these data, prophylactic anticoagulation should be considered for all hospitalized patients with COVID-19 not requiring ICU-level care. No study, however, has evaluated the efficacy of thromboprophylaxis in the prevention of stroke among patients with COVID-19. For patient discharged home from the hospital, there is no evidence of improved outcomes in continuing anticoagulation post-discharge [83]. Clinical trials are currently ongoing and clinical judgment should be used to evaluate the bleeding risk of anticoagulation in patients with COVID-19 [84].
Thrombolysis

Intravenous tPA appears to be safe and effective for patients with COVID-19 and acute ischemic stroke [74, 85]. This recommendation, however, comes with the caveat that patients with COVID-19 have been found to have a higher prevalence of elevated inflammatory (elevated C-RP and D-dimer), [86, 87] and these markers have been previously associated with increased risk of post-tPA intracerebral hemorrhage among patients with acute ischemic stroke without COVID-19 infection [88]. Another aspect that needs to be considered is hepatic dysfunction in patients with COVID-19 patients [89]. Some COVID-19 patients may present with elevated transaminitis, but normal coagulation markers (prothrombin time PT, international normalized ratio INR, and activated partial thromboplastin time APTT) [89]. Intravenous tPA is hepatically cleared, and in patients with reduced hepatic function, there is a potential increase in serum tPA levels and increased risk of ICH [90]. Moreover, advanced hepatic dysfunction may be associated with coagulopathy with elevation in PT, INR, and thromcytopenia [90]. Ultimately, delivery of tPA should follow standard guidelines as recommend by the American Heart Association/American Stroke Association and FDA [91]. We do not recommend basing the decision of whether to give IV tPA based on thromboelastography, D-dimer level, or any other testing that is not standard among patients with acute ischemic stroke without COVID-19.

Mechanical Thrombectomy

As mentioned above, LVOs are common in COVID-19 patients [13, 17, 20, 21]. LVOs place large cerebral territories at ischemic risk and cause high rates of morbidity and mortality without further treatment. An abundance of high-quality data over the past few years has shown the efficacy of mechanical endovascular thrombectomy for improving clinical outcomes in patients with LVOs [19]. Mechanical thrombectomy (MT) is an available and helpful procedure in patients with LVO due to COVID-19. A recent meta-analysis showed that MT is safe and equally successful in patients with COVID-19-related LVOs as it is in patients without COVID-19 who have LVOs [92]. Controversies still exist on MT for posterior circulation strokes and in particular clinical trials have failed to show superiority of MT compared to best medical management [93, 94]. An ongoing trial is looking at MT for basilar artery occlusion (BAO) between 6 and 24 h from symptom onset [95]. It remains uncertain whether COVID-19 patients with BAO may benefit from MT.
Systems of Care During the COVID-19 Pandemic

Stroke Patients’ Accessibility to Urgent Stroke Treatment

During the COVID-19 pandemic, patients’ accessibility to the emergency medical care has dramatically changed. At the height of the pandemic, the emergency department (ED) volume was down approximately 50% in the USA [96]. Paradoxically, despite the heightened risk for thrombotic complications, including stroke, the number of stroke admission decreased during the height of the pandemic. This “COVID-19 stroke paradox” was thought to be due to patients’ increased fear of entering hospitals and contracting COVID-19 [15, 46, 97, 98]. Patients were more likely to prioritize avoiding exposure to SARS-CoV2 and ignore symptoms that may have previously led them to visit a hospital [99]. This fear of contracting COVID-19 led to decreased stroke admissions throughout the world [15, 96, 97]. For example, a study from central and south Texas showed that patient admission, treatment, and discharge volumes for acute stroke treatment decreased significantly when COVID-19-related shelter-at-home orders were issued [100]. With the increased patients’ fear of accessing the EDs and the governments’ suggestion to access the ED only if truly necessary, the patients with stroke who came to the ED were often more severe and/or outside the window for acute stroke interventions including tPA and mechanical thrombectomy [10, 100–102]. Delays in presentation to the hospital were not just related to fear of SARS-CoV2 exposure, but also use of social distancing and decreased human contact, especially among older persons, thus reducing the chance of prompt identification of a neurological deficit [2, 31•]. Finally, among patients hospitalized with COVID-19, delays in identification of stroke were due to frequent use of sedatives and paralytics which precluded prompt identification of stroke symptoms [2, 6]. Perhaps it is not a surprise then that initially there was a decreased overall rate of hospitalization for stroke during the COVID-19 pandemic, despite the virus’ propensity for thrombotic complications [97]. All the aforementioned changes due to the COVID-19 pandemic, including the patients’ fear to access the ED, the increased proportion of strokes arriving to the ED outside the treatment window, and the difficulties in identifying stroke symptoms in hospitalized COVID-19 patients, have posed significant challenges to stroke care for which we continue to seek new avenues to combat.

Health Care System Logistics

The COVID-19 pandemic has affected the protocols and safety guidelines put in place to protect patients, providers, and health care workers. Tight infection control, redeployment, and social distancing regulations have impacted the ability of stroke teams to promptly provide acute stroke interventions [91]. Application of personal protective equipment (PPEs), stringent sterilization requirements, and additional safety measures similarly delayed stroke
teams in assessing and treating patients presenting with acute stroke symptoms [91, 103]. Finally, the shortage of hospital beds, and in particular of intensive care beds, has also impacted stroke care; post-tPA or mechanical thrombectomy patients were often relegated to non-ICU beds, limiting the frequency of neurological assessments in patients at high risk for complications [91, 104].

Regarding thrombectomy, the need of COVID-19 testing prior to entering the angiography suite, and the difficulties in obtaining consent due to the “no visitor hospital policies” caused significant delays in delivery endovascular therapy [74, 103, 104]. Another important consideration is whether COVID-19 patients should undergo mechanical thrombectomy under general anesthesia as opposed to monitored anesthesia care (MAC). While a consensus statement from the Society for Neuroscience in Anesthesiology and Critical Care has proposed that general anesthesia may be required in COVID-19 patients undergoing thrombectomy to reduce exposure risk, [105] preliminary data have shown that general anesthesia and intubation result in increased door-to-reperfusion time (138 vs 100 min) and are associated with higher in-hospital mortality (RR 1.87) and lower probability of functional independence at discharge (RR 0.53) [106]. In light of these findings, whenever possible, and if safe, MAC should be considered even for COVID-19 positive patients undergoing mechanical thrombectomy.

The Post-pandemic Lessons

The COVID-19 pandemic has impacted stroke care [107]. While there have been increased delays in the recognition and treatment of acute ischemic stroke in the ED, there have also been improvements in the delivery of care for outpatients, and specifically for patients in remote regions. The pandemic has led to major advances in the use of telemedicine: a readily available technology that has allowed patients to receive access to a neurologist or stroke expert. For example, patients in rural areas, who often have limited access to neurologists and stroke care in general, now have access to these experts in the comfort of their home or in their local EDs. While the pandemic has caused major economic, political, and social problems, a benefit has been the realization that telemedicine is an easy-to-use, expeditious way to provide specialty-level expertise with an improved utilization of healthcare resources. We believe that this positive outcome from the COVID-19 pandemic is here to stay and will lead to an overall reduction in the worldwide burden of cerebrovascular disease and neurological disability.
Declarations

Conflict of Interest
Marialaura Simonetto declares that she has no conflict of interest. Paul Wechsler declares that he has no conflict of interest. Alexander Merkler declares that he has no conflict of interest.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance

1. Zhao J, Rudd A, Liu R. Challenges and potential solutions of stroke care during the coronavirus disease 2019 (COVID-19) outbreak. Stroke. 2020;51:1356–7.
2. Bikdeli B, Madhavan MV, Jimenez D, et al. COVID-19 and thrombotic or thromboembolic disease: implications for prevention, antithrombotic therapy, and follow-up. J Am Coll Cardiol. 2020;75:2950–73.
3. Fridman S, Bres Bullrich M, Jimenez-Ruiz A, Costantini P, Shah P, Just C, Vela-Duarte D, Linfante I, Shariﬁ-Razavi A, Karimi N, Bagur R, Debicki DB, Gofton TE, Steven DA, Sposato LA. Stroke risk, phenotypes, and death in COVID-19: systematic review and newly reported cases. Neurology. 2020;95(24):e3373–85. https://doi.org/10.1212/WNL.00000000000010851.
4. Ellul MA, Benjamin L, Singh B, Lant S, Michael BD, Easton A, Kneen R, Defres S, Sejvar J, Solomon T. Neurological associations of COVID-19. Lancet Neurol. 2020;19(9):767–83. https://doi.org/10.1016/S1474-4422(20)30221-0.
5. Lodigiani C, Iapichino G, Carenzo L, Cecconi M, Ferrazzi P, Sebastiani T, et al. Venous and arterial thromboembolic complications in COVID-19 patients admitted to an academic hospital in Milan. Italy Thromb Res. 2020;191:145–147. https://doi.org/10.1016/j.thromres.2020.04.024.
6. Klok FA, Kruip MJHA, van der Meer NJM, Arbous MS, Gommers DAMPJ, Kant KM, Kaptein FHI, van Paassen J, Stals MAM, Huisman MV, Endeman H. Incidence of thrombotic complications in critically ill ICU patients with COVID-19. Thromb Res. 2020;191:145–147.
7. Katsanos AH, Palaidio N, Zand R, Yaghil S, Kamel H, Navi B, Turc G, Romoli M, Sharma VK, Mavridis D, Shahjouei S. The impact of SARS-CoV-2 on stroke epidemiology and care: a meta-analysis. Ann Neurol. 2021;89(2):380–388. https://doi.org/10.1002/ana.25967. This is a meta-analysis evaluating the incidence of stroke among patients hospitalized with COVID-19.
8. Nannoni S, de Groot R, Bell S, Markus HS. Stroke in COVID-19: a systematic review and meta-analysis. Int J Stroke. 2021;16(2):137–49. https://doi.org/10.1177/1747493020972922.
9. Mao L, Jin H, Wang M, Hu Y, Chen S, He Q, Chang J, Hong C, Zhou Y, Wang D, Miao X. Neurological manifestations of hospitalized patients with coronavirus disease 2019 in Wuhan, China. JAMA Neurol 2020;77(6):683–690. This is one of the original publications describing neurological complications of COVID-19.
10. Sezgin M, Ekozolgu E, Yesilot N, Coban O. Stroke during COVID-19 pandemic. Noro Psikiyat Ars. 2020;57(2):83–4. https://doi.org/10.29399/npa.27196.
11. Boehme C, Hannay E, Sampath R. SARS-CoV-2 testing for public health use: core principles and considerations for defined use settings. Lancet Glob Health. 2021;9(3):e247–9. https://doi.org/10.1016/S2214-109X(21)00006-1.
12. Merkler AE, Parikh NS, Mr S, Gupta A, Kamel H, Lin E, Lantos J, Schenck EL, Goyal P, Bruce SS, Kahan J. Risk of ischemic stroke in patients with coronavirus disease 2019 (COVID-19) vs patients with influenza. JAMA Neurol. 2020;77:11–17. https://doi.org/10.1001/jamaneurol.2020.2730. This study compares the risk of stroke among patients with COVID-19 versus influenza.
13. Majidi S, Fifi JT, LadnerTR, et al. Emergent large vessel occlusion stroke during New York city’s COVID-19 outbreak: clinical characteristics and paraclinical findings. Stroke. 2020;51:2656–63. https://doi.org/10.1161/STROKEAHA.120.030397.
14. Violi F, Pastori D, Cangemi R, et al. Hypercoagulation and antithrombotic treatment in coronavirus 2019: A new challenge. Thromb Haemost. 2020;120:949–56. https://doi.org/10.1055/s-0040-1710317.
15. Rudiosso 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;51:1991–9. https://doi.org/10.1161/STROKEAHA.120.030329.
16. Cavallieri F, Marti A, Fasano A, et al. Prothrombotic state induced by COVID-19 infection as trigger for stroke in young patients: a dangerous association. eNeurologicalSci. 2020;20(2020247). https://doi.org/10.1016/j.ensci.2020.100247.
17. Lakomkin N, Dhamoon M, Carroll K, Singh IP, Tuhrim S, Lee J, Fifi JT, Mocco J. Prevalence of large vessel occlusion in patients presenting with acute ischemic stroke: a 10-year systematic review of the literature. J Neurointerv Surg. 2019;11(3):241–5. https://doi.org/10.1136/neurintsurg-2018-014239.

18. Duloquin G, Graber M, Garnier L, Crespy V, Comby PO, Baptiste L, Mohr S, Delport B, Guéniat J, Blanc-Labarre C, Hervieu-Bègue M, Ossey GV, Giroud M, Béjr Y. Incidence of acute ischemic stroke with visible arterial occlusion: a population-based study (Dijon stroke registry). Stroke. 2020;51(7):2122–30. https://doi.org/10.1161/STROKEAHA.120.029949.

19. Rennert RC, Wali AR, Steinberg JA, et al. Epidemiology, natural history, and clinical presentation of large vessel ischemic stroke. Neurosurgery. 2019;85(suppl_1):S4-S8. https://doi.org/10.1093/neuros/myz042.

20. Fifi JT. COVID-19 related stroke in young individuals. Lancet Neurol. 2020;19(9):713–5. https://doi.org/10.1016/S1474-4422(20)30272-6.

21. Majidi S, Fifi JT, Ladner TR, Lara-Reyna J, Yaeger KA, Yim B, Belani P, Schefflein J, Kihira S, et al. COVID-19 is an independent risk factor for acute ischemic stroke. AJNR Am J Neuroradiol. 2020. https://doi.org/10.3174/ajnr.A6650.

22. Hantoushzadeh S, Nabavian SM, Soleimani Z, Soleimani A. Cardiovascular complications of COVID-19: a position paper of the ESC working group for atherosclerosis and vascular biology, and the ESC council of basic cardiovascular science. Cardiovasc Res. 2020;116(14):2177–84. https://doi.org/10.1093/cvr/cvaa230.

23. Helms J, Kremer S, Merdji H, Clere-Jehl R, Schenck M, Kummerlen C, Collange O, Boulay C, Fafi-Kremer S, Ohana M, Anheim M, Meziani F. Neurologic features in severe SARS-CoV-2 infection. 2020. N Engl J Med. 2020. An initial report of the neurological complications of COVID-19.

24. Castro-Verdes M, Gkouma A, Wort J, Ridge C, Mirsadraee S, Padley S, Sheikh A, Singh S. Corona virus disease 2019 in situ arterial and venous thrombosis in critically ill patients: a case series. Eur Heart J Case Rep. 2020;4(6):1–7. https://doi.org/10.1093/ehjcr/ytaa470.

25. Mandal AKJ, Kho J, Ioannou A, Van den Abbeele K, Missouris CG. Covid-19 and in situ pulmonary artery thrombosis. Respir Med. 2021;176:106176. https://doi.org/10.1016/j.rmed.2020.106176.

26. Bilaloglu S, Aphiyanaphongs Y, Jones S, Iturrate E, Hochman J, Berger JS. Thrombosis in hospitalized patients with COVID-19 in a New York City health system. JAMA. 2020;324:799–801. An initial report of the thrombotic manifestations of COVID-19.

27. Singhania N, Bansal S, Nimnattakit PA, Singhania G. Current: Overview on hypercoagulability in COVID-19. Am J Cardiovasc Drugs. 2020;20(5):393–403. https://doi.org/10.1007/s40256-020-00431-z.

28. Begbie M, Notley C, Tinlin S, Sawyer L, Lillicrap D. The factor VIII acute phase response requires the participation of NFkappaB and C/EBP. Thromb Haemost. 2020;84(2):16–22.

29. Ranucci M, Ballotta A, Di Dedda U, Bayshnikova E, Dei Poli M, Resta M, Falco M, Albano G, Menicanti L. The procoagulant pattern of patients with COVID-19 acute respiratory distress syndrome. J Thromb Haemost. 2020;18(7):1747–51.

30. Montalvan V, Toledo JD, Nugent K. Mechanisms of stroke in coronavirus disease 2019. J Stroke. 2020;22:282–3. https://doi.org/10.5853/jos.2020.01802.

31. Esenwa C, Cheng NT, Luna J, Willey J, Boehme AK, Kirchoff-Torres K, Labovitz D, Liberman AL, Mabie P, Moncrief K, Soetanto A, Lendaris S, Seiden J, Goldman I, Altschul D, Holland R, Benton J, Dardick J, Fernandez-Torres J, Flomenbaum D, Lu J, Malaviya A, Patel N, Toma A, Lord A, Ishida K, Torres J, Snyder T, Frontera J, Yaghi S. Biomarkers of coagulation and inflammation in COVID-19-associated ischemic stroke. Stroke. 2021. https://doi.org/10.1161/STROKEAHA.120.030335.
42. Hart RG, Diener HC, Coutts SB, Easton JD, Granger CB, O’Donnell MJ, Sacco RL, Connolly SJ. Cryptogenic stroke/ESUS international working group. Embolic strokes of undetermined source: the case for a new clinical construct. Lancet Neurol. 2014;13(4):429–438. https://doi.org/10.1016/S1474-4422(13)70310-7.

43. Guo T, Fan Y, Chen M. Cardiovascular implications of fatal outcomes of patients with coronavirus disease 2019 (COVID-19). JAMA Cardiol. 2020;5(7):811–818.

44. Wang D, Hu B, Hu C. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China. JAMA. 2020;323(11):1061–9.

45. Ntaios G, Pearce LA, Veltkamp R. Potential embolic sources and outcomes in embolic stroke of undetermined source in the NAVIGATE-ESUS trial. Stroke. 2020;51:7197–804.

46. Siegler JE, Cardona P, Arenillas JE, et al. Cerebrovascular events and outcomes in hospitalized patients with COVID-19: the SVIN COVID-19 multinational registry. Int J Stroke. 2020;1747493020959216:1747493020959216. https://doi.org/10.1177/1747493020959216.

47. Vu D, Ruggiero M, Choi WS, Masri D, Flyer M, Shyknevsky I. Three unsuspected CT diagnoses of COVID-19. Emerg Radiol. 2020;27(3):229–31.

48. Sharifi-Razavi A, Karimi N, Rouhani N. COVID-19 and intracerebral haemorrhage: causative or coincidental? New Microbes New Infect. 2020;27(35):100669–100669.

49. Benger M, Williams O, Siddiqui J, Sztriha L. Intracerebral haemorrhage and COVID-19: clinical characteristics from a case series. Brain Behav Immun. 2020;88:940–4. https://doi.org/10.1016/j.bbi.2020.06.005.

50. Morassi M, Bagatto D, Cobelli M, D’Agostini S, Gigli GL, Bnà C, et al. Stroke in patients with SARS-CoV-2 infection: case series. J Neurol. 2020. https://doi.org/10.1007/s00415-020-09885-2.

51. Li Y, Wang M, Zhou Y, et al. Acute cerebrovascular disease following COVID-19: a single center, retrospective, observational study. https://ssrn.com/abstract=3550025.

52. Kvernland A, Kumar A, Yaghi S, Raz E, Frontera J, Lewis A, Czeisler B, Kahn DE, Zhou T, Ishida K, Torres J, Riina HA, Shapiro M, Nossek E, Nelson PK, Tanweer O, Gordon D, Jain R, Dekhkharghani S, Henninger N, de Havenon A, Grozy BM, Lord A, Melmed K. Anticoagulation use and hemorrhagic stroke in SARS-CoV-2 patients treated at a New York healthcare system. Neurocrit Care. 2021;34(3):748–59. https://doi.org/10.1007/s12028-020-10077-0.

53. Princiotta Cariddi L, Tabae Davamandi P, Carimati F, et al. Reversible encephalopathy syndrome (RES) in a COVID-19 patient. J Neurol. 2020;267(11):3157–60. https://doi.org/10.1007/s00415-020-10001-7.

54. Kishfy L, Casasola M, Bananekh P, et al. Posterior reversible encephalopathy syndrome (PRES) as a neurological association in severe covid-19. J Neurol Sci. 2020;414(116943). https://doi.org/10.1016/j.jns.2020.116943.

55. Parauda SC, Gao V, Gewirz AN, et al. Posterior reversible encephalopathy syndrome in patients with COVID-19. J Neurol Sci. 2020;416:117019.

56. Fugate JERA. Posterior reversible encephalopathy syndrome: clinical and radiological manifestations, pathophysiology, and outstanding questions. Lancet Neurol. 2015;14(9):914–25.

57. Parauda SC, Gao V, Gewirz AN, Parikh NS, Merkler AE, Lantos J, White H, Leifer D, Navi BB, Segal AZ. Posterior reversible encephalopathy syndrome in patients with COVID-19. J Neurol Sci. 2020;416:117019. https://doi.org/10.1016/j.jns.2020.117019.

58. Berlin DA, Gulick RM, Martinez FJ. Severe covid-19. N Engl J Med. 2020;383(25):2451–60. https://doi.org/10.1056/NEJMcp2009575.

59. da Rosa Mesquita R, Francelino Silva Junior LC, Santos Santana FM, Farias de Oliveira T, Campos Alcântara R, Monteiro Arnozo G, Rodrigues da Silva Filho E, Caidino Dos Santos AG, Oliveira da Cunha EJ, Salgueiro de Aquino SH, Freire de Souza CD. Clinical manifestations of COVID-19 in the general population: systematic review. Wien Klin Wochenschr. 2021;133(7–8):377–382. https://doi.org/10.1007/s00508-020-01760-4.

60. Patel P, Khandelwal P, Gupta G, Singla A. COVID-19 and cervical artery dissection- a causative association? J Stroke Cerebrovasc Dis. 2020;29(10):105047. https://doi.org/10.1016/j.jstrokecerebrovasdis.2020.105047.

61. Zubair AS, McAlpine LS, Gardin T, Farhadian S, Kuruvilla DE, Spudich S. Neuropathogenesis and neurologic manifestations of the coronaviruses in the age of coronavirus disease 2019: A review. JAMA Neurol. 2020.

62. Divani AAS, Napoli MD, Lattanzi S, Hussain MS, Biller J. Coronavirus disease 2019 and stroke: clinical manifestations and pathophysiological insights. J Stroke Cerebrovasc Dis. 2020;29(8).

63. Thompson A, Morgan C, Smith P, Jones C, Ball H, Coulthard EJ, Moran E, Szewczyk-Krolikowski K, Rice CM. Cerebral venous sinus thrombosis associated with COVID-19. Pract Neurologist 2020;8:002678. https://doi.org/10.1136/practneurologist-2020-002678.

64. Medichera CB, Pauley RA, de Havenon A, Yaghi S, Ishida K, Torres JL. Cerebral venous sinus thrombosis in the COVID-19 pandemic. Neuroophthalmol J. 2020;40(4):457–62. https://doi.org/10.1097/WNO.0000000000001122.

65. Tu TM, Goh C, Tan YK, et al. Cerebral venous thrombosis in patients with COVID-19 infection: a case series and systematic review. J Stroke Cerebrovasc Dis. 2020;29(12):105379. https://doi.org/10.1016/j.jstrokecerebrovasdis.2020.105379.

66. Ostovan VR, Foroughi R, Rostami M, Almasi-Dooghaee M, Esmaili A, Zabidi M, Bakhshi M, Salehi MS, Zafarmand SS, Mafi E, Keshavarzian A, Ziv J, Hooshmand M, Shokri Mardani S, Mozaffar M, Abrishamzadeh H, Mardani S, Azarpazhooh MR, Zand R, Mohammadi A, Azarpazhooh MR, Zand R, Hooshmandi E, Borhani-Haghighi A. Cerebral venous sinus thrombosis associated with COVID-19: a case series and literature review. J Neurol. 2021;22(1):1–12. https://doi.org/10.1007/s00415-021-10450-8.

67. Klein DE, Libman R, Kirsch C, Arora R. Cerebral venous thrombosis: atypical presentation of COVID-19 in the young. J Stroke Cerebrovasc Dis. 2020. https://doi.org/10.1016/j.jstrokecerebrovasdis.2020.104989.

68. Perry RJ, Smith CJ, Roffe C, et al. Characteristics and outcomes of COVID-19-associated stroke: A UK multicentre case-control study. J Neurol Neurosurg Psychiatry. 2021;92:242–8. https://doi.org/10.1136/jnnp-2020-324927.

69. Jensen-Kondering U, Huhn dorf M, Jansen O. Neurothrombectomy in patients with covid-19. A systematic
review and meta-analysis. Presented at International Stroke Conference; March 17–19. Abstract LB P8. 2021.

70. Tan YK, Goh C, Leow AST, et al. COVID-19 and ischemic stroke: a systematic review and meta-summary of the literature. J Thromb Thrombolysis. 2020;50(3):587–95. https://doi.org/10.1007/s11239-020-02228-y.

71. Khaira S, Schefflein J, Mahmoudi K, Rigney B, N Delman B, Mocco J, Doshi A, Belani P. Association of coronavirus disease (COVID-19) with large vessel occlusion strokes: a case-control study. AJR. 2021;216(1):10–15. https://doi.org/10.2214/AJR.20.23847.

72. Zhou Y, Hong C, Chang J, Xia Y, Jin H, Li Y, Mao L, Wang Y, Zhang L, Pan C, Hu J, Huang M, Wang D, Chen S, Hu B. Intravenous thrombolysis for acute ischaemic stroke during COVID-19 pandemic in Wuhan, China: a multicentre, retrospective cohort study. J Neurol Neurosurg Psychiatry. 2021;92(2):226–8. https://doi.org/10.1136/jnnp-2020-34041.

73. Qureshi AI, Siddiq F, French BR, Gomez CR, Jani V, Hassan AE, Suri MF. Effect of COVID-19 pandemic on mechanical thrombectomy for acute ischemic stroke treatment in united states. J Stroke Cerebrovasc Dis. 2021;29(10):157068. https://doi.org/10.1016/j.jstrokecerevasdis.2021.106020.

74. Qureshi AI, Baskett WI, Huang W, Shyu D, Myers D, Raju M, Lobanova I, Suri MF, Naqvi SH, French BR, Siddiq F, Gomez CR, Shyu CR. Acute ischemic stroke and COVID-19: an analysis of 27,676 patients. Stroke. 2021;52(3):905–12. https://doi.org/10.1161/STROKEAHA.120.031786.

75. Bruce SS, Kahan H, Hu Q, Santillan A, Navi BB, Parikh NS, Mir S, Schweitzer AD, Segal AZ. Missed cerebrovascular events during prolonged sedation for COVID-19 pneumonia. J Clin Neurosci. 2021;86:180–3. https://doi.org/10.1016/j.jocn.2021.01.008.

76. Qin C, Zhou L, Hu Z, et al. Clinical characteristics and outcomes of COVID-19 patients with a history of stroke in wuhan, china. Stroke. 2020;51:2219–23. https://doi.org/10.1161/STROKEAHA.120.030365.

77. Siegler JE, Zha AM, Czap AL, Ortega-Gutierrez S, Faroqui M, Liebeskind DS, Desai SM, Hassan AE, Starosciak AK, Linfante I, Rai V, Thon JM, Then R, Heslin ME, Thau L, Khandelwal P, Mohammaden MH, Haussen DC, Nogueira RG, Jillava DL, Nahaj F, Kalavvaoi A, Nguyen TN, Zaidat O, Jovin TG, Jovin TG. Influence of the COVID-19 pandemic on treatment times for acute ischemic stroke: the society of vascular and interventional neurology multicenter collaboration. Stroke. 2021;52(1):40–7. https://doi.org/10.1161/STROKEAHA.120.032789.

78. Al Kasab S, Almallouhi E, Alavieh A, Levitt MR, Jabbour P, Suri MF. Effect of COVID-19 on mechanical thrombectomy during the COVID-19 pandemic: Insights from STAR and ENRG. J Neurointerv Surg. 2020;12(11):1039–1044. https://doi.org/10.1136/neurintsurg-2020-016671.
MB, Liporace IL, de Oliveira Twardowsky A, Maia LN, Machado FR, de Matos Soeiro A, Conceição-Souza GE, Armaganian L, Guimarães PO, Rosa RG, Azevedo LCP, Alexander JH, Avezzum A, Cavalcanti AB, Berwanger O, ACTION Coalition COVID-19 Brazil IV Investigators. Therapeutic versus prophylactic anticoagulation for patients admitted to hospital with COVID-19 and elevated D-dimer concentration (ACTION): an open-label, multicentre, randomized, controlled trial. Lancet. 2021;397(10291):2253–2263. https://doi.org/10.1016/S0140-6736(21)02034-4.

83. Lemos ACB, do Espírito Santo DA, Salvetti MC, Gilio RN, Agra LB, Pazin-Filho A, Miranda CH. Therapeutic versus prophylactic anticoagulation for severe COVID-19: a randomized phase II clinical trial (HESACOVID). Thromb Res. 2020;196:359–366. https://doi.org/10.1016/j.thromres.2020.09.026.

84. Gavioli EM, Sikorska G, Man A, et al. Current perspectives of anticoagulation in patients with COVID-19. J Cardiovasc Pharmacol. 2020;76:146–50. https://doi.org/10.1097/FJC.0000000000000861.

85. Powers WJ, Rabinstein AA, Ackerson T, et al. Guidelines for the early management of patients with acute ischemic stroke: 2019 update to the 2018 guidelines for the early management of acute ischemic stroke: a guideline for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2019;50:e344–418.

86. Helsinki Stroke Thrombolysis Registry Group. Body temperature, blood infection parameters, and outcome of thrombolysis-treated ischemic stroke patients. Int J Stroke. 2013;8:632–8.

87. Hsu P-J, Chen C-H, Yeh S-J, Tsai L-K, Tang S-C, Jeng J-S. High plasma C-reactive protein level and risk of anticoagulation in patients with COVID-19. J Cardiovasc Pharmacol. 2020;76:146–50. https://doi.org/10.1097/FJC.0000000000000861.

88. Jiang J, Tan C, Zhou W, Peng W, Zhou X, Du J, Wang H, Mo L, Liu X, Chen L. Plasma C-reactive protein level and outcome of acute ischemic stroke patients treated by intravenous thrombolysis: a systematic review and meta-analysis. Eur Neurol. 2021;84(3):145–50. https://doi.org/10.1159/000340999.

89. China Medical Treatment Expert Group for Covid-19. Clinical characteristics of coronavirus disease 2019 in China. N Engl J Med. 2020.

90. Stravitz RT, Lismam T, Luketic VA, et al. Minimal effects of acute liver injury/acute liver failure on hemostasis as assessed by thromboelastography. J Hepatol. 2012;56:129–36.

91. AHA/ASA Stroke Council Leadership. Temporary emergency guidance to US stroke centers during the coronavirus disease 2019 (COVID-19) pandemic: on behalf of the American Heart Association/American Stroke Association Stroke Council Leadership. Stroke. 2020;51(6):1910–2. https://doi.org/10.1161/STROKEAHA.120.030023.

92. Al-Smadi AS, Mach JC, Abrol S, Luqman A, Chamiraju P, Abujudeh H. Endovascular thrombectomy of COVID-19-related large vessel occlusion: a systematic review and summary of the literature. Curr Radiol Rep. 2021;9(4):4. https://doi.org/10.1007/s40134-021-00379-1.

93. Schonewille W. BEST evidence on mechanical thrombectomy for patients with vertebrobasilar occlusion. Lancet Neuro. 2020;19(2):102–3. https://doi.org/10.1016/S1474-4422(19)30477-6.

94. Langezaal LCM, van der Hoeven EJRI, Mont’Alverne FA, de Carvalho JF, Lima FO, Dippel DWJ, van der Lugt A, Lo RTH, Boiten J, Lycklama A Nijeholt GJ, Staal S, van Zwam WH, Nederkoorn PJ, Majoie CBLM, Gerber JC, Mazighi M, Piotin M, Zini A, Vallone S, Hofmeijer J, Martins SO, Nolte CH, Szabo K, Dias FA, Abud DG, Wermer MJH, Remmers MJM, Schneider H, Rueckert CM, de Laat KE, Yoo AJ, van Doornmaal PJ, van Es ACGM, Emmer BJ, Michel P, Puetz V, Audebert HJ, Pontes-Neto OM, Vos IA, Kappelle LJ, Algra A, Schonewille WJ. BASICS Study Group. Endovascular therapy for stroke due to basilar-artery occlusion. N Engl J Med. 2021;384(20):1910–1920. https://doi.org/10.1056/NEJMoa2030297.

95. Li C, Wu C, Wu L, Zhao W, Chen J, Ren M, Yao C, Yan X, Dong C, Song H, Ma Q, Duan J, Zhang Y, Zhang H, Jiao L, Wang Y, Jovin TG, Ji X, BAOCHE Investigators. Basilar artery occlusion Chinese endovascular trial: protocol for a prospective randomized controlled study. Int J Stroke. 2021;28:17474930211040923. https://doi.org/10.1177/17474930211040923.

96. Laura E. Wong, MD, PhD, Jessica E. Hawkins, MSEd, Simone Langness, MD, Karen L. Murrell, MD, Patricia Iris, MD & Amanda Sammann, MD, MPH. Where are all the patients? Addressing covid-19 fear to encourage sick patients to seek emergency care. NEJM Catalyst Innovations in Care Delivery. 2020;2(4).

97. Aguiar de Sousa D, Sandset EC, Elkind MSV. The curious case of the missing strokes during the COVID-19 pandemic. Stroke. 2020;51:1921–1923. https://doi.org/10.1161/STROKEAHA.120.030792.

98. Sharma M, Lioutas V-A, Madsen T, et al. Decline in stroke alerts and hospitalisations during the COVID-19 pandemic. Stroke Vasc Neurol. 2020. https://doi.org/10.1136/svn-2020-000441.

99. July JPR. Impact of the coronavirus disease pandemic on the number of strokes and mechanical thrombectomies: a systematic review and meta-analysis. J Stroke Cerebrovasc Dis. 2020;29(11):105185. https://doi.org/10.1016/j.jstrokecerebrovasdis.2020.105185.

100. Dula AN, Gealoglo Brown G, Aggarwal A, Clark KL. Decrease in stroke diagnoses during the COVID-19 pandemic: where did all our stroke patients go? JMIR Aging. 2020;3(2):e21608. https://doi.org/10.2196/21608.

101. Markus HSBM. COVID-19 and stroke-A global world stroke organization perspective. Int J Stroke. 2020;15(4):361–4. https://doi.org/10.1177/1747493020923472.

102. Oxley TJ, Mocco J, Majidi S, Kellner CP, Shoilah H, Singh IH, Singh J, De Leacy RA, Shigematsu T, Ladner TR, Vaeger KA, Skliut M, Weinberger J, Dangayach NS, Bederson JB, Tuhrim S, Fifi JT. Large-vessel stroke as a presenting feature of covid-19 in the young. N Engl J Med. 2020;382(20):e60.

103. Baracchini C, Pieroni A, Viaro F, Cianci V, Cattelan AM, Tiberio I, Munari M, Causin F. Acute stroke management pathway during coronavirus-19 pandemic. Neur Sci. 2020;41(5):1003–5. https://doi.org/10.1007/s10072-020-04375-9.
104. Wira CR, Goyal M, Southerland AM, Sheth KN, McNair ND, Khostravani H, Leonard A, Panagos P. AHA/ASA Stroke Council Science Subcommittees: Emergency Neurovascular Care (ENCC), Telestroke and the Neurovascular Intervention Committees; and on behalf of the Stroke Nursing Science Subcommittee of the AHA/ASA Cardiovascular and Stroke Nursing Council. Pandemic guidance for stroke centers aiding COVID-19 treatment teams. Stroke. 2020;51(8):2587–2592. https://doi.org/10.1161/STROKEAHA.120.030749.

105. Sharma D, Rasmussen M, Han R, et al. Anesthetic management of endovascular treatment of acute ischemic stroke during COVID-19 pandemic: consensus statement from Society for Neuroscience in Anesthesiology & Critical Care (SNACC): endorsed by Society of Vascular & Interventional Neurology (SVIN), Society of NeuroInterventional Surgery (SNIS), Neurocritical Care Society (NCS), European Society of Minimally Invasive Neurological Therapy (ESMINT) and American Association of Neurological Surgeons (AANS) and Congress of Neurological Surgeons (CNS) Cerebrovascular Section. J Neurosurg Anesthesiol. 2020;32:193–201. https://doi.org/10.1097/ANA.0000000000000688.

106. Al Kasab S, Almallouhi E, Alawieh A, et al. International experience of mechanical thrombectomy during the COVID-19 pandemic: insights from StAR and ENRG. J Neurointerv Surg. 2020;12:1039–44. https://doi.org/10.1136/neurintsurg-2020-016671.

107. Zhao J, Wang Y, Fisher M, Liu R. Slower recovery of outpatient clinics than inpatient services for stroke and other neurological diseases after COVID-19 pandemic. CNS Neurosci Ther. 2020;26(12):1322–6. https://doi.org/10.1111/cns.13459.

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