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Multimodal monitoring to guide neurosurgical intervention in high-grade aneurysmal subarachnoid hemorrhage: illustrative case

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BACKGROUND Multimodal monitoring to guide medical intervention in high-grade aneurysmal subarachnoid hemorrhage (aSAH) is well described. Multimodal monitoring to guide surgical intervention in high-grade aSAH has been less studied.

OBSERVATIONS Intracranial pressure (ICP), brain lactate to pyruvate ratio (L/P ratio), and brain parenchymal oxygen tension (pO_2) were used as surrogates for clinical status in a comatose man after high-grade aSAH. Acute changes in ICP, L/P ratio, and pO_2 were used to identify brain injury from both malignant cerebral edema and delayed cerebral ischemia, respectively, and decompressive hemicraniectomy with clot evacuation and intraarterial nimodipine were used to treat these conditions. The patient showed marked improvement in multimodal parameters following each intervention and eventually recovered to a modified Rankin score of 2.

LESSONS In patients with a limited neurological examination due to severe acute brain injury in the setting of aSAH, multimodal monitoring can be used to guide surgical treatment. With prompt, aggressive, maximal medical and surgical interventions, otherwise healthy individuals may retain the capacity for close to full recovery from seemingly catastrophic aSAH.

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KEYWORDS subarachnoid hemorrhage; multimodal monitoring; delayed cerebral ischemia; vasospasm; cerebral microdialysis

Patients suffering from high-grade aneurysmal subarachnoid hemorrhage (aSAH) continue to have a poor prognosis despite decades of research and scientific advancements. Following treatment of the ruptured aneurysm, managing symptomatic elevations in intracranial pressure (ICP) and attempting to identify and treat delayed cerebral ischemia (DCI) remain paramount goals in the management of these patients. However, in high-grade aSAH, identifying symptomatic ICP crises and DCI events may be challenging because patients are frequently stuporous or comatose, with little to no opportunity for neurological examination.

Multimodal monitoring using cerebral microdialysis catheters, ICP monitors (either through external ventricular drains or standalone ICP monitors), and intraparenchymal brain oxygenation sensors has been thought to hold promise in identifying evolving brain injuries in stuporous or comatose patients with aSAH. These devices allow for semicontinuous monitoring of intracranial metabolic, perfusion, and oxygen transport dynamics and can act as useful surrogates for the clinical examination.[1] The data obtained from multimodal monitoring systems has been used to guide medical interventions, including insulin therapy, enteral nutrition, cerebral perfusion pressure targets, detection of early cerebral ischemia, red blood cell transfusion, and targeted management of PaO^2/FiO^2 via normobaric hyperoxia, in patients with acute brain injury.[1] Of particular use from the neurosurgical perspective has been the increasing amount of data implicating rises in the brain microfluid lactate-to-pyruvate ratio (L/P ratio) as an early predictor of DCI.[2,3] Guidelines exist for using multimodal data to initiate and titrate treatments aimed at optimizing intracranial pressure and cerebral perfusion pressure, glycemic control, oxygen therapy, and blood transfusions.[4] Nonetheless, high-level evidence supporting their use in guiding medical management remains limited.[5]

ABBREVIATIONS aSAH = aneurysmal subarachnoid hemorrhage; CSF = cerebrospinal fluid; CT = computed tomography; DCI = delayed cerebral ischemia; GCS = Glasgow Coma Scale; ICP = intracranial pressure; L/P ratio = lactate-to-pyruvate ratio; MCA = middle cerebral artery; pO_2 tension = parenchymal oxygen tension; SAH = subarachnoid hemorrhage.

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In comparison to its use in guiding medical treatments, the existing literature has comparatively little to say with respect to the role that multimodal monitoring values can play in the surgical management of patients with high-grade aSAH. Here we report the use of multimodal monitoring of ICP, intraparenchymal brain oxygenation, and cerebral microdialysis data to guide surgical treatment decisions in a comatose patient with a high-grade aSAH.

Illustrative Case

A 46-year-old man presented via emergency medical services to a local community hospital after collapsing at home. After securing the patient's airway with endotracheal intubation, computed tomography (CT) of the head showed thick subarachnoid blood filling the basal cisterns with diffuse brain edema and early hydrocephalus, concerning for high-grade aSAH. The patient was airlifted to our tertiary care center for neurosurgical evaluation. On arrival, physical examination demonstrated a Hunt and Hess grade 5 presentation, with positive brainstem reflexes but closed eyes and extensor posturing to central stimulation. CT angiography demonstrated a modified Fisher grade 4 SAH due to a ruptured right middle cerebral artery (MCA) bifurcation aneurysm. A left frontal external ventricular drain was placed for cerebrospinal fluid (CSF) diversion and ICP monitoring.

Given the location of the aneurysm at the MCA bifurcation and the associated hematoma, a right frontotemporal craniotomy for aneurysm clipping and clot evacuation was considered. However, given the patient's poor clinical grade (Hunt and Hess grade 5), hemodynamic lability, and lack of mass effect from the hematoma, we pursued endovascular treatment of the aneurysm. The aneurysm was treated with primary coiling, and a Raymond Roy grade I occlusion was achieved.

Following aneurysmal treatment, there was no change to the patient's dismal neurological examination, with closed eyes, sluggishly reactive pupils, and minimal extension in his extremities to stimulation when off sedation. In patients who are able to follow commands or display purposeful movement in at least one of their upper extremities, we typically monitor for symptoms of DCI using hourly neurological checks. In comatose patients, we instead monitor surrogates of intracerebral function, including ICP, intraparenchymal oxygen tension, and cerebral L/P ratio as a means of identifying new or evolving brain damage. In this case, ICP was measured through the external ventricular drainage catheter placed on admission, whereas pO_2 and brain metabolism were monitored with Licox and microdialysis catheters, respectively.

Early on postbleed day 2, ICP and the L/P ratio both began to display clear upward trends to critical values, with L/P peaking at 40.2 cm H_2O and ICP peaking at 30 cm H_2O. Simultaneously, intraparenchymal oxygen values showed a clear downtrend, from a high of 17 kPa on postbleed day 1 to a low of 6 kPa on postbleed day 2 (Fig. 1). Although there was no change in the patient's neurological examination, based on these worrying trends in multimodal monitoring values, the decision was made to perform surgery for a right decompressive hemicraniectomy and intracranial hemorrhage evacuation.

Follow surgery, the ICP normalized and the L/P ratio remained <30 for approximately 18 hours. However, on postbleed day 3, the patient again experienced simultaneous increases in ICP (to 30 cm H_2O from 14 cm H_2O), L/P ratio (to 40 cm H_2O from 26.8 cm H_2O), and a decrease in pO_2 (to 6 kPa from 11 kPa) (Fig. 1). CT angiogram showed severe diffuse vasospasm of the bilateral internal carotid arteries, MCAs, and anterior cerebral arteries. Based on the multimodal data suggesting evolving brain injury and the imaging data identifying obvious areas of vasospasm, the patient received intraarterial verapamil treatment.

Following intraarterial verapamil treatment, ICP and L/P ratios normalized, with no values >20 or 30 cm H_2O, respectively. pO_2 also displayed marked improvement, with values consistently >20 kPa after treatment (Fig. 1).

After these treatments, the patient displayed slow but steady clinical improvement, eventually opening his eyes and following simple commands. He was successfully extubated on postbleed day 16, and the external ventricular drain was weaned without need for permanent CSF diversion on postbleed day 18. The patient was eventually discharged to an acute inpatient rehabilitation facility. He returned to the hospital 3 months later for successful autologous cranioplasty. At the time of his cranioplasty, his neurological examination demonstrated only residual moderate left hemiparesis (modified Rankin Scale score 2). He continues to follow up at our cerebrovascular clinic almost 1 year later with stable neurological examination, and he has returned to work.

Discussion

Observations

Despite significant advances in the surgical and endovascular management of ruptured intracranial aneurysms, the morbidity and mortality of high-grade aSAH remain high. The prompt identification and treatment of ICP crises and symptomatic DCI are of key importance.[6]

DCI is defined as clinical deterioration or cerebral infarction not attributable to other causes.[7] Here, "clinical deterioration" is formally defined as the occurrence of a focal neurological deficit or a decrease of at least 2 points on the Glasgow Coma Scale (GCS) that lasts for 1 hour, is not apparent immediately after aneurysm occlusion, and cannot be attributed to other causes. "Cerebral infarction" is defined as the presence of infarction on CT or magnetic resonance imaging within 6 weeks of SAH that was not present 24 to 48 hours after aneurysm treatment and cannot be attributed to surgical treatment.

It is difficult to apply the definition of DCI to high-grade SAH because it is often challenging to identify new focal neurological deficits or objective decreases in GCS scores because patients are almost by definition intubated and comatose.[8] From this perspective, invasive multimodal monitoring, in which a combination of ICP, intraparenchymal oxygenation, and cerebral microdialysis values are used to monitor for new or evolving brain injury, holds promise in the diagnosis and management of clinically significant ICP crises and DCI in these patients.

Here, we provide an example of how, despite no change in the patient's neurological examination, multimodal monitoring of ICP, cerebral microdialysis parameters, and brain oxygenation were used to identify an ICP crisis as well as symptomatic cerebral vasospasm, both of which were treated with timely and effective neurosurgical interventions.

Lessons

In patients with severe acute brain injury without meaningful clinical examinations, multimodal monitoring values can be used to guide surgical treatment. With prompt, aggressive, maximal medical and surgical interventions, otherwise healthy individuals retain the capacity for close to full recovery from seemingly catastrophic aSAH. Although our observations support the use of multimodal monitoring in the neurosurgical management of high-grade aSAH, limitations remain. Current technology allows for localized sampling of

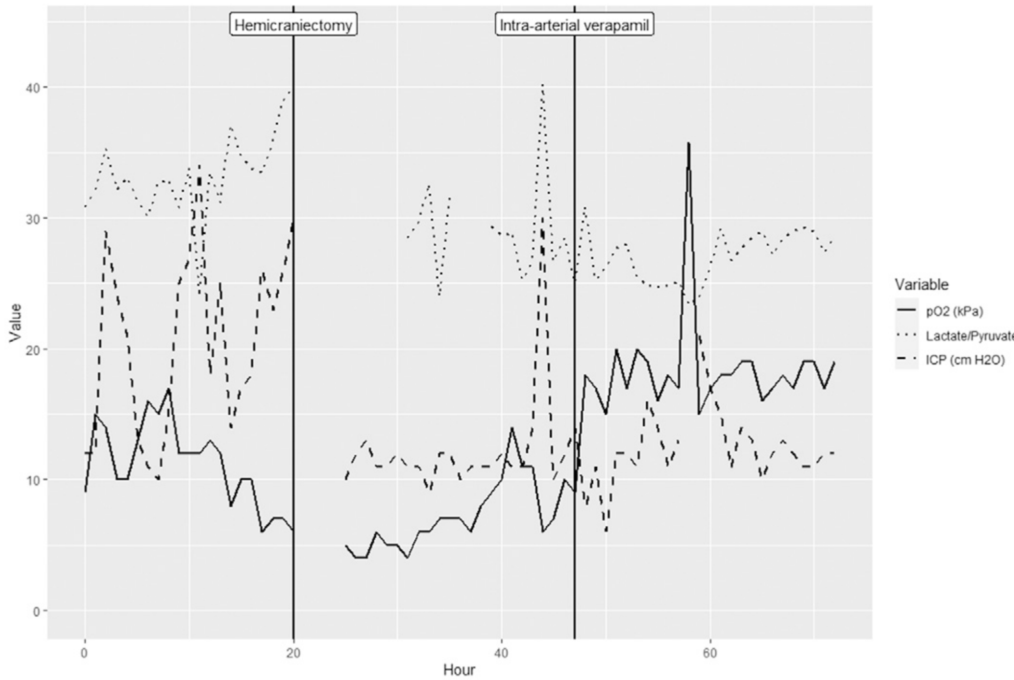

FIG. 1. ICP, L/P ratio, and pO_2 during the first 21 hours of monitoring. A steady rise in ICP and L/P ratio was accompanied by a slow but steady decrease in pO_2 during the first 24 hours. This was taken to indicate developing brain injury from extended ICP crises, motivating decompressive hemicraniectomy and hematoma evacuation. Twenty hours after hemicraniectomy, simultaneous spikes in ICP and cerebral microdialysis L/P ratio and a drop in intracranial oxygen tension were observed. These were taken to represent possible symptomatic DCI. CT angiography demonstrated severe diffuse vasospasm throughout the anterior circulation, and the patient was taken to the angiography suite for intraarterial verapamil administration. Immediately following intervention, L/P ratios stabilized at $<$30, while oxygen tension had a sustained rise.

what is often known to be a diffuse cerebral state. Indeed, double hemispheric sampling has shown that unilateral sampling often results in missed DCI.[9] In addition to further development of the underlying technology, prospective trials testing the use of multimodal monitoring in the neurosurgical management of high-grade aSAH are needed. However, in the absence of future data, anecdotal reports of improved outcome for these patients may support its continued use.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Kolb, Wolfson, Munich. Acquisition of data: Kolb, Wolfson, Da Silva. Analysis and interpretation of data: Kolb, Wolfson, Munich. Drafting the article: Kolb, Wolfson. Critically revising the article: all authors. Reviewed submitted version of manuscript: Kolb, Wolfson, Da Silva. Approved the final version of the manuscript on behalf of all authors: Kolb. Statistical analysis: Kolb.

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