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 (pO2) were used as surrogates for clinical status in a comatose man after high-grade aSAH. Acute changes in ICP, L/P ratio, and pO2 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.

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 PaO2/FiO2 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
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 airifted 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 intracranial function, including ICP, intraparenchymal oxygen tension, and cerebral L/P ratio as a means of identifying new focal neurological deterioration.6 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.6

Following intraarterial verapamil treatment, ICP and L/P ratios normalized, with no values >20 or 30 cm H2O, respectively. PO2 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.2 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.

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**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 multimodal data suggesting evolving brain injury and the imaging data identifying obvious areas of vasospasm, the patient received intraarterial verapamil treatment.

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what is often known to be a diffuse cerebral state. Indeed, double hemispheric sampling has shown that unilateral sampling often results in missed DCI. 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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