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Paul Nyquist, Neeraj Naval, and Rafael J. Tamargo

INTRODUCTION: THE EPIDEMIOLOGY AND COST OF ANEURYSMAL SUBARACHNOID HEMORRHAGE

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Brad E. Zacharia, Zachary L. Hickman, Bartosz T. Grobelny, Peter DeRosa, Ivan Kotchetkov, Andrew F. Ducruet, and E. Sander Connolly Jr

Aneurysmal subarachnoid hemorrhage (aSAH) is a form of hemorrhagic stroke that affects up to 30,000 individuals per year in the United States. The incidence of aSAH has been shown to be associated with numerous nonmodifiable (age, gender, ethnicity, family history, aneurysm location, size) and modifiable (hypertension, body mass index, tobacco and illicit drug use) risk factors. Although early repair of ruptured aneurysms and aggressive postoperative management has improved overall outcomes, it remains a devastating disease, with mortality approaching 50% and less than 60% of survivors returning to functional independence. As treatment modalities change and the percentage of minority and elderly populations increase, it is critical to maintain an up-to-date understanding of the epidemiology of SAH.

Outcome and Cost of Aneurysmal Subarachnoid Hemorrhage

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AndréA. le Roux and M. Christopher Wallace

Aneurysmal subarachnoid hemorrhage (aSAH) is a neurosurgical catastrophe. It affects 33,000 patients in the United States annually and has a mortality rate of 50% to 60% at 30 days. Half of the survivors are dependent. Outcome is closely related to the level of consciousness at the time of presentation, global cerebral edema, subarachnoid blood load as seen on CT, and rehemorrhage. Age, hyperglycemia, and medical complications are associated with worse outcomes. The cost impact factor of this condition is high from a financial perspective as well as from a patient perspective. Care givers show increased morbidity when compared with the nonaffected community. Early aggressive treatment of good grade patients seems to provide the best outcome for this serious condition.

SURGICAL AND INTERVENTIONAL RADIOLOGICAL TREATMENT IN ANEURYSMAL SUBARACHNOID HEMORRHAGE

Surgical Management of Aneurysmal Subarachnoid Hemorrhage

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Geoffrey P. Colby, Alexander L. Coon, and Rafael J. Tamargo

Aneurysmal subarachnoid hemorrhage (aSAH) is a common and often devastating condition that requires prompt neurosurgical evaluation and intervention. Modern management of aSAH involves a multidisciplinary team of subspecialists, including vascular neurosurgeons, neurocritical care specialists and, frequently, neurointerventional radiologists. This team is responsible for stabilizing the patient on presentation, diagnosing the offending ruptured aneurysm, securing the aneurysm, and managing the patient through a typically prolonged and complicated hospital

course. Surgical intervention has remained a definitive treatment for ruptured cerebral aneurysms since the early 1900s. Over the subsequent decades, many innovations in microsurgical technique, adjuvant maneuvers, and intraoperative and perioperative medical therapies have advanced the care of patients with aSAH. This report focuses on the modern surgical management of patients with aSAH. Following a brief historical perspective on the origin of aneurysm surgery, the topics discussed include the timing of surgical intervention after aSAH, commonly used surgical approaches and craniotomies, fenestration of the lamina terminalis, intraoperative neurophysiological monitoring, intraoperative digital subtraction and fluorescent angiography, temporary clipping, deep hypothermic cardiopulmonary bypass, management of acute hydrocephalus, cerebral revascularization, and novel clip configurations and microsurgical techniques. Many of the topics highlighted in this report represent some of the more debated techniques in vascular neurosurgery. The popularity of such techniques is constantly evolving as new studies are performed and data about their utility become available.

Hydrocephalus After Aneurysmal Subarachnoid Hemorrhage

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Hydrocephalus is a common and potentially devastating complication of aneurysmal subarachnoid hemorrhage (SAH). Its incidence is approximately 20% to 30%, and its onset can be acute, within 48 hours after SAH, or rarely chronic, occurring in a delayed fashion weeks and even months after the hemorrhage. Early recognition of its signs and symptoms and accurate interpretation of computed tomography (CT) studies are important for the management of patients with SAH. Clinically, a poor neurologic grade has the highest correlation with an increased incidence of hydrocephalus. Radiographically, the bicaudate index on CT studies has emerged as the best marker of this condition. Although further studies are needed to understand the complex pathophysiology of this condition, hydrocephalus after SAH can be treated effectively using current technology.

Endovascular Treatment of Aneurysmal Subarachnoid Hemorrhage

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Monica Pearl, Lydia Gregg, and Philippe Gailloud

Aneurysmal subarachnoid hemorrhage is a deadly disease associated with high morbidity and mortality. Surgical clipping has been the gold standard treatment for more than 70 years. Endovascular therapy is now accepted as a valid alternative therapeutic modality. The authors' approach emphasizes collaboration between endovascular and surgical specialists. The array of new endovascular techniques has extended beyond the Guglielmi Detachable Coil to include new stents and flow-diverting devices. The future promises expansion of the number of types of aneurysms that are treatable with endovascular techniques.

Endovascular Management of Cerebral Vasospasm

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Ben McGuinness and Dheeraj Gandhi

Cerebral vasospasm is a cause of significant morbidity and mortality in patients with subarachnoid hemorrhage (SAH). Most cases of vasospasm can be managed medically. Medical strategies for treatment include hemodynamic augmentation to improve cerebral perfusion pressure and medical therapy to prevent or reduce cerebral vasospasm. In patients with acute neurological deterioration, imaging assessment is essential to triage those patients appropriate for aggressive medical or endovascular therapy. Such imaging assessment can be performed with many radiologic techniques such as transcranial Doppler, computed

tomography (CT), magnetic resonance imaging, and single-photon emission CT (SPECT). Advanced CT applications like CT angiography and CT perfusion are gaining popularity and playing an increasingly important role in the decision making. Endovascular techniques for treatment of vasospasm include intra-arterial administration of vasodilators and intracranial angioplasty. This article discusses the use of these endovascular techniques in the management of vasospasm and provides a current review of literature. Sustained efficacy of intra-arterial vasodilators is less well established at this time, and repeated treatments may be necessary. Balloon angioplasty is an effective technique in treating vasospasm and results in durable clinical improvement. It should be used judiciously, however, given a small risk of vessel rupture associated with intracranial angioplasty. The goal of angioplasty should be improvement of vessel caliber to augment flow rather than to achieve a picture-perfect result.

NON-INVASIVE IMAGING IN ANEURYSMAL SUBARACHNOID HEMORRHAGE

The Role of Transcranial Doppler Ultrasonography in the Diagnosis and Management of Vasospasm After Aneurysmal Subarachnoid Hemorrhage

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Scott A. Marshall, Paul Nyquist, and Wendy C. Ziai

Transcranial Doppler ultrasonography (TCD) is a tool employed by the neurosurgeon and neurointensivist in the management of vasospasm in the intensive care unit after aneurysmal subarachnoid hemorrhage. A review of the current indications, monitoring parameters, indices, and relevance of modern TCD technology is provided, as well as algorithms for the use of TCD ultrasonography in the management of patients with subarachnoid hemorrhage. Other current uses of TCD ultrasonography are also discussed in the setting of neurocritical care.

Noninvasive Imaging Techniques in the Diagnosis and Management of Aneurysmal Subarachnoid Hemorrhage

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Scott A. Marshall, Sudhir Kathuria, Paul Nyquist, and Dheeraj Gandhi

Aneurysmal subarachnoid hemorrhage (aSAH) is a devastating condition, requiring prompt diagnosis and therapeutic intervention as well as close monitoring for the development of complications including vasospasm (VS). Although digital subtraction angiography is still considered the gold standard for the diagnosis of aSAH (and vasospasm), new and less invasive modalities are emerging including ultrasound, CT, CT angiography and CT perfusion, and MR imaging. The current evidence for the use of these newer modalities is described for the diagnosis of aSAH and the management of its sequelae including VS.

THE MEDICAL MANAGEMENT OF ANEURYSMAL SUBARACHNOID HEMORRHAGE AND ITS SEQUELLA

Medical Complications After Subarachnoid Hemorrhage

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Katja E. Wartenberg and Stephan A. Mayer

The prevention and management of medical complications are important for improving outcomes after subarachnoid hemorrhage (SAH). Fever, anemia requiring transfusion, hyperglycemia, hyponatremia, pneumonia, hypertension, and neurogenic cardiopulmonary dysfunction occur frequently after SAH. There is increasing evidence that acute hypoxia and extremes of blood pressure can exacerbate brain injury during the acute phase of bleeding. There are promising strategies to minimize these complications. Randomized controlled trials are needed to

evaluate the risks and benefits of these and other medical management strategies after SAH.

Cerebral Salt Wasting: Pathophysiology, Diagnosis, and Treatment

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Alan H. Yee, Joseph D. Burns, and Eelco F.M. Wijdicks

Cerebral salt wasting (CSW) is a syndrome of hypovolemic hyponatremia caused by natriuresis and diuresis. The mechanisms underlying CSW have not been precisely delineated, although existing evidence strongly implicates abnormal elevations in circulating natriuretic peptides. The key in diagnosis of CSW lies in distinguishing it from the more common syndrome of inappropriate secretion of antidiuretic hormone. Volume status, but not serum and urine electrolytes and osmolality, is crucial for making this distinction. Volume and sodium repletion are the goals of treatment of patients with CSW, and this can be performed using some combination of isotonic saline, hypertonic saline, and mineralocorticoids.

Risk Factors and Medical Management of Vasospasm After Subarachnoid Hemorrhage

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Christos Lazaridis and Neeraj Naval

Vasospasm is a major cause of morbidity and mortality following aneurysmal subarachnoid hemorrhage. This article reviews the risk factors for vasospasm; the various methods for diagnosing vasospasm including the conventional 4-vessel angiography, computed tomographic angiography, and computed tomographic perfusion; the methods to detect vasospasm before clinical onset (including transcranial Doppler ultrasonography); and the recent emergence of multimodality monitoring. A discussion of medical treatment options in the setting of vasospasm is also included; the prophylactic use of “neuroprotectants” such as nimodipine, statins, and magnesium and the role of hemodynamic augmentation in vasospasm amelioration, including the use of inotropic support in addition to traditional triple-H therapy, are discussed.

INFLAMMATION AND VASOSPASM IN SUBARACHNOID HEMORRHAGE

Inflammation and Cerebral Vasospasm After Subarachnoid Hemorrhage

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Gustavo Pradilla, Kaisorn L. Chaichana, Stanley Hoang, Judy Huang, and Rafael J. Tamargo

Morbidity and mortality of patients with aneurysmal subarachnoid hemorrhage (aSAH) is significantly related to the development of chronic cerebral vasospasm. Despite extensive clinical and experimental research, the pathophysiology of the events that result in delayed arterial spasm is not fully understood. A review of the published literature on cerebral vasospasm that included but was not limited to all PubMed citations from 1951 to the present was performed. The findings suggest that leukocyte-endothelial cell interactions play a significant role in the pathophysiology of cerebral vasospasm and explain the clinical variability and time course of the disease. Experimental therapeutic targeting of the inflammatory response when timed correctly can prevent vasospasm, and supplementation of endothelial relaxation by nitric oxide-related therapies and other approaches could result in reversal of the arterial narrowing and improved outcomes in patients with aSAH.

Biomarkers and Vasospasm After Aneurysmal Subarachnoid Hemorrhage

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J. Dedrick Jordan and Paul Nyquist

Subarachnoid hemorrhage from the rupture of a saccular aneurysm is a devastating neurological disease that has a high morbidity and mortality not only from the initial

hemorrhage, but also from the delayed complications, such as cerebral vasospasm. Cerebral vasospasm can lead to delayed ischemic injury 1 to 2 weeks after the initial hemorrhage. Although the pathophysiology of vasospasm has been described for decades, the molecular basis remains poorly understood. With the many advances in the past decade in the development of sensitive molecular biological techniques, imaging, biochemical purification, and protein identification, new insights are beginning to reveal the etiology of vasospasm. These findings will not only help to identify markers of vasospasm and prognostic outcome, but will also yield potential therapeutic targets for the treatment of this disease. This review focuses on the methods available for the identification of biological markers of vasospasm and their limitations, the current understanding as to the utility and prognostic significance of identified biomarkers, the utility of these biomarkers in predicting vasospasm and outcome, and future directions of research in this field.