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Endovascular Neurosurgery: Innovations, Techniques, and AI

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Introduction

This systematic review and meta-analysis evaluated the efficacy and safety of endovascular treatment for unruptured intracranial aneurysms. It found that endovascular coiling and stent-assisted coiling are effective treatments, offering favorable outcomes with acceptable complication rates, although long-term follow-up is essential to monitor recurrence and retreatment rates. The findings underscore the importance of patient selection and procedural expertise in achieving optimal results [1].

This systematic review and meta-analysis evaluated the safety and efficacy of flow diverters in treating intracranial aneurysms. The findings indicate that flow diversion offers high rates of aneurysm occlusion with acceptable complication profiles, particularly for large or complex aneurysms that are challenging to treat with traditional coiling. The review underscores the expanding role of flow diverters and the need for continued advancements in device technology and patient selection [4].

This review provides an overview of complications associated with endovascular treatment of intracranial aneurysms, including thromboembolic events, aneurysm rupture, and device-related issues. It discusses key risk factors and strategies for prevention and management of these complications, emphasizing meticulous procedural technique, appropriate antiplatelet regimens, and prompt recognition of adverse events to improve patient safety and clinical outcomes [6].

This review discusses the evolution and current state of mechanical thrombectomy for acute ischemic stroke, emphasizing its role as the gold standard for large vessel occlusion. It explores various thrombectomy devices, patient selection criteria, and emerging techniques, highlighting the need for rapid assessment and intervention to improve patient outcomes. Future directions include advancements in imaging, artificial intelligence integration, and expanding treatment windows [2].

This study reported on a single-center experience with endovascular embolization for cerebral arteriovenous malformations (AVMs), demonstrating its effectiveness as a primary treatment or an adjunct to surgery or radiosurgery. It highlights the importance of precise embolization techniques and careful patient selection to achieve favorable clinical and angiographic outcomes while minimizing complications, particularly in complex AVM cases [3].

This systematic review summarizes the current evidence on endovascular treatment for spinal arteriovenous malformations (SAVMs), evaluating its safety and efficacy across different SAVM types. It concludes that endovascular embolization is a vital treatment modality, either curative or palliative, for SAVMs, offering significant neurological improvement or stabilization. The review highlights the challenges and the need for individualized treatment strategies given the complex anatomy and diverse presentations of SAVMs [7].

This review focuses on the role of endovascular treatment, primarily angioplasty and stenting, for symptomatic intracranial atherosclerotic disease (ICAD). It discusses the current indications, technical considerations, and outcomes, emphasizing that while medical management remains the first-line therapy, endovascular interventions may be beneficial in carefully selected patients who fail aggressive medical treatment. The article also points out the need for further robust clinical trials to define the precise role of these interventions [8].

This review explores the unique aspects and challenges of pediatric endovascular neurosurgery, covering conditions like aneurysms, AVMs, and vein of Galen malformations. It highlights the complexities associated with treating younger patients, including smaller vessel sizes, rapid growth, and long-term implications of radiation exposure. The article emphasizes the multidisciplinary approach required and the need for specialized expertise and tailored devices to achieve optimal outcomes in this vulnerable population [9].

This review highlights the growing importance of simulation-based training in endovascular neurosurgery to enhance technical skills and patient safety. It discusses various simulation modalities, from physical models to virtual reality platforms, and their role in improving trainee proficiency before live patient procedures. The article emphasizes the need for standardized curricula and objective assessment methods to integrate simulation effectively into neurosurgical training programs [5].

This scoping review explores the burgeoning applications of artificial intelligence (AI) in endovascular neurosurgery, focusing on areas like image analysis for lesion detection, surgical planning, and outcome prediction for stroke and aneurysm treatments. It highlights how AI can enhance diagnostic accuracy, personalize treatment strategies, and improve workflow efficiency. The review also discusses the challenges associated with data integration and validation, underscoring the need for rigorous research to fully realize AI's transformative potential in the field [10].

Description

The field of endovascular neurosurgery has made significant strides in treating various neurovascular conditions. For unruptured intracranial aneurysms, both endovascular coiling and stent-assisted coiling have proven to be effective treatments, yielding favorable outcomes and acceptable complication rates. Contin-

uous long-term follow-up is essential to track recurrence and retreatment rates, highlighting the need for careful patient selection and expert procedural execution to achieve the best results [1]. Expanding on aneurysm treatment, flow diverters offer high rates of aneurysm occlusion with manageable complication profiles, especially beneficial for large or complex aneurysms that are challenging for traditional coiling methods. This innovative approach continues to broaden the scope of treatable aneurysms, necessitating ongoing advancements in device technology and refined patient selection [4]. However, these sophisticated interventions are not without risks. Complications such as thromboembolic events, aneurysm rupture, and device-related issues are associated with endovascular treatment of intracranial aneurysms. Effective management involves understanding key risk factors, employing meticulous procedural techniques, using appropriate antiplatelet regimens, and promptly recognizing adverse events to enhance patient safety and clinical outcomes [6].

For acute ischemic stroke, mechanical thrombectomy stands as the gold standard for large vessel occlusion. It emphasizes rapid assessment and intervention, which are critical for improving patient outcomes. Research continues to explore diverse thrombectomy devices, refine patient selection, and develop new techniques. Future directions include leveraging advancements in imaging, integrating Artificial Intelligence (AI), and potentially extending treatment windows [2]. Beyond stroke, endovascular embolization has shown considerable effectiveness for cerebral arteriovenous malformations (AVMs), whether used as a primary treatment or an adjunct to surgery or radiosurgery. Success in complex AVM cases relies heavily on precise embolization techniques and careful patient selection, which help achieve positive clinical and angiographic results while minimizing complications [3].

Similarly, endovascular treatment for spinal arteriovenous malformations (SAVMs) is a vital, often curative or palliative, modality that can lead to significant neurological improvement. The complex anatomy and varied presentations of SAVMs necessitate highly individualized treatment strategies [7]. Endovascular treatment, primarily through angioplasty and stenting, also plays a role in managing symptomatic intracranial atherosclerotic disease (ICAD). While medical management remains the initial approach, these interventions can benefit carefully selected patients who have not responded to aggressive medical treatment. More robust clinical trials are needed to precisely define the role and indications for these interventions [8].

Addressing the unique challenges of pediatric endovascular neurosurgery is critical, covering conditions like aneurysms, AVMs, and vein of Galen malformations in younger patients. The complexities include smaller vessel sizes, rapid growth, and concerns regarding long-term radiation exposure. A multidisciplinary approach, specialized expertise, and tailored devices are indispensable for achieving optimal outcomes in this vulnerable population [9]. The growing complexity and precision required in endovascular neurosurgery underscore the importance of simulation-based training. This training enhances technical skills and patient safety, utilizing a range of modalities from physical models to virtual reality platforms. Effective integration into neurosurgical training programs demands standardized curricula and objective assessment methods to improve trainee proficiency before live patient procedures [5].

Looking to the future, Artificial Intelligence (AI) is rapidly emerging as a transformative force in endovascular neurosurgery. A scoping review indicates its burgeoning applications in critical areas such as image analysis for lesion detection, surgical planning, and the prediction of outcomes for stroke and aneurysm treatments. AI promises to significantly enhance diagnostic accuracy, enable personalized treatment strategies, and boost workflow efficiency. However, the full realization of AI's potential in this field depends on successfully addressing significant challenges related to data integration and the rigorous validation of AI models through extensive research [10].

Conclusion

Endovascular neurosurgery has advanced significantly, addressing a range of complex cerebrovascular conditions. For unruptured intracranial aneurysms, treatments like endovascular coiling, stent-assisted coiling, and flow diverters demonstrate efficacy with acceptable complication rates, though long-term monitoring for recurrence is key. Careful procedural technique and risk factor management are crucial to minimize complications such as thromboembolic events and rupture. In acute ischemic stroke, mechanical thrombectomy is now the gold standard for large vessel occlusion, emphasizing rapid assessment and intervention to improve patient outcomes. This evolving field incorporates advancements in imaging and Artificial Intelligence (AI). Endovascular embolization serves as a vital treatment for both cerebral and spinal arteriovenous malformations (AVMs), requiring precise techniques and patient selection for good outcomes. For symptomatic intracranial atherosclerotic disease (ICAD), endovascular interventions like angioplasty and stenting can benefit selected patients who fail aggressive medical management, though further clinical trials are needed. Pediatric endovascular neurosurgery presents unique challenges due to smaller vessel sizes, rapid growth, and radiation exposure, demanding a multidisciplinary approach and specialized devices. Simulation-based training is increasingly important to enhance technical skills and patient safety. Looking ahead, AI is poised to transform endovascular neurosurgery by improving image analysis, surgical planning, and outcome prediction for stroke and aneurysm treatments, despite challenges in data integration and validation.

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Conflict of Interest

None.

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