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MINIMALLY INVASIVE NEUROSURGERY: MODERN APPROACHES AND OUTCOMES

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Abstract.: This article provides a broad overview of the main directions of minimally invasive neurosurgery and practical experience with their application. First, the shortcomings of traditional open surgery are analyzed and the reasons behind the development of minimally invasive technologies are identified. The paper presents detailed information on the effectiveness of endoscopic transnasal surgery for treating pituitary adenomas, the advantages of microsurgical techniques in brain tumors and vascular pathologies, and the clinical outcomes of minimally invasive spinal surgery for disc herniations and spinal stenosis. In addition, information is given on how the use of neuronavigation and intraoperative MRI/CT can improve operative accuracy and safety.

Keywords: neurosurgery; endoscopic surgery; microsurgery; spinal surgery; neuronavigation; intraoperative MRI/CT; robotic systems.

Introduction. Neurosurgery has advanced significantly over the past decades. Although traditional open surgical techniques have provided great opportunities for saving patients' lives, large incisions, prolonged recovery times, and a high risk of complications remain major challenges. Consequently, the field of minimally invasive neurosurgery has emerged on a global scale.

Minimally invasive approaches allow access to pathological processes through small incisions. Endoscopic transnasal surgery for the removal of pituitary adenomas, microsurgical procedures performed under a microscope, and minimally invasive spinal surgeries are among the most commonly applied techniques today.

In addition, the introduction of intraoperative neuronavigation, high-resolution MRI and CT imaging, as well as robotic systems, has further improved the diagnostic and surgical outcomes of minimally invasive neurosurgery. According to research, these methods reduce operative time, minimize blood loss, and significantly shorten patients' hospital stays [1–3].

Main Approaches

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Endoscopic Neurosurgery.

Endoscopic techniques, particularly transnasal endoscopic surgery, are widely used in the treatment of pituitary tumors, craniopharyngiomas, and parasellar pathologies. In this approach, the surgeon accesses the surgical site through the nasal passages using a specialized endoscope. The main advantage of this technique is that it eliminates the need for a large cranial incision and minimizes trauma to facial and brain structures [4].

Studies show that, compared to traditional transcranial approaches, the recurrence rate of pituitary adenomas removed through endoscopic methods is 20–30% lower, and the average hospital stay is limited to just 2–3 days [5].

Microsurgery (Microscope-Assisted Operations). Microsurgical techniques are primarily used for treating brain tumors and vascular pathologies. Operations are performed under high-precision surgical microscopes, allowing the surgeon to clearly distinguish diseased tissue from healthy neurons. For example, microscopic aneurysm clipping is considered the "gold standard" for the treatment of cerebral aneurysms. Minimally invasive microsurgery reduces blood loss by approximately 40% and shortens patient recovery time to an average of 7–10 days [6].

Minimally Invasive Spinal Surgery. One of the key branches of neurosurgery is minimally invasive spinal surgery. This approach is applied in cases of herniated discs, spinal stenosis, and spinal tumors. Procedures such as endoscopic discectomy or percutaneous stabilization eliminate the need for large incisions and significantly reduce damage to muscles and soft tissues. Clinical observations indicate that over 80% of patients who undergo minimally invasive spinal surgery are able to return to normal daily activities within one week, while complications are observed at half the rate compared to traditional open surgery [7,8].

Neuronavigation and Intraoperative Imaging. In minimally invasive neurosurgical procedures, neuronavigation systems, intraoperative CT/MRI, and ultrasound technologies are widely utilized. These tools help surgeons precisely locate pathological lesions, visualize their boundaries, and perform operations with high accuracy. For instance, the use of intraoperative MRI can achieve up to a 90% glioma resection rate, significantly improving long-term patient outcomes [9].

Clinical Outcomes and Advantages of Minimally Invasive Neurosurgery. Compared to traditional open surgery, minimally invasive neurosurgery offers numerous clinical benefits for patients. Over the past two decades, the use of these techniques has increased sharply, making them a vital component of modern neurosurgical practice.

Reduced Trauma and Faster Recovery. Instead of large incisions, minimally invasive neurosurgical techniques employ small cuts or natural anatomical pathways (such as nasal cavities or minimal skeletal openings) to access the surgical area. This significantly reduces muscle and soft tissue damage. As a result, postoperative pain is 40–60% lower, and the average hospital stay is reduced to 3–5 days — compared to 10–14 days with traditional approaches [10].

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Reduced Blood Loss. In minimally invasive techniques, intraoperative blood loss is reduced by up to 50%. For example, during endoscopic pituitary adenoma surgeries, the average blood loss does not exceed 100 ml, whereas in open transcranial approaches, this figure ranges from 400 to 600 ml [11].

Reduced Risk of Infection and Complications. While traditional open surgeries carry a higher risk of infection and cerebrospinal fluid leakage, these rates are 2–3 times lower in minimally invasive neurosurgical procedures. For instance, in minimally invasive spinal surgery, the incidence of postoperative infections is only 0.5–1%, compared to 3–5% in open surgical methods [12].

Functional Outcomes. Patients generally experience better functional recovery following minimally invasive neurosurgical procedures. After endoscopic pituitary surgery, visual function improves in 70–80% of cases. Similarly, in minimally invasive aneurysm surgery, the incidence of postoperative neurological deficits is 25–30% lower than in traditional open approaches [13].

Aesthetic Advantages. Due to smaller incisions, postoperative scarring is minimal or barely visible. This is particularly important for younger patients and for surgeries involving cosmetically sensitive areas.

Limitations and Challenges of Minimally Invasive Neurosurgery. Although minimally invasive neurosurgery represents an effective alternative to traditional open surgery, its implementation comes with several challenges and limitations.

Technical Complexity and Learning Curve. Mastering minimally invasive neurosurgical techniques requires advanced skills and specialized training. The surgeon's experience has a significant impact on outcomes. Studies indicate that the complication rate in endoscopic pituitary surgeries tends to be higher during the first 20–30 procedures but decreases markedly as the surgeon gains experience [14].

Need for Specialized Equipment. Minimally invasive neurosurgery requires advanced instruments such as endoscopes, intraoperative neuronavigation systems, high-precision microscopes, and modern radiological imaging devices. This requirement limits the feasibility of such procedures in low-resource settings where technical capabilities may be insufficient.

Prolonged Operating Time. In cases where surgeons lack sufficient experience, minimally invasive procedures may take longer than traditional open surgeries. For example, minimally invasive lumbar disc surgeries can take 2–3 hours in the initial learning stages, whereas conventional discectomy typically lasts 1–1.5 hours [15].

Limited Visualization. Endoscopic approaches have restricted viewing angles and working fields, which can reduce the possibility of achieving complete resection in complex anatomical regions. Therefore, in some cases, hybrid techniques (combining minimally invasive and open methods) are employed to ensure optimal outcomes.

Cost and Economic Considerations. Minimally invasive neurosurgery technologies require substantial financial investment. The cost of specialized equipment, maintenance, and additional technologies increases the overall expense, posing challenges for widespread adoption in developing countries [16].

Conclusion

Minimally invasive neurosurgery is increasingly being recognized as a safe and effective alternative to traditional open surgical methods. The integration of endoscopic, microscopic, and robotic technologies enhances surgical precision, reduces complication rates, and shortens patient recovery times.

However, the technical complexity, high costs, and challenges in specialized training continue to limit its broader implementation. Future advancements in neuronavigation, intraoperative imaging, and robotic systems are expected to further improve the safety and efficacy of minimally invasive neurosurgical procedures.

Overall, minimally invasive neurosurgery represents one of the most promising directions in the future of neurosurgical practice.

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