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Advances and the Future of Skull Base Surgery

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Skull base surgery is a specialized field dedicated to managing complex lesions at the skull base, including tumors, inflammatory conditions, vascular malformations, and traumatic injuries. The intricate anatomy of this region, which contains essential neurovascular structures and delicate cranial nerves, presents significant surgical challenges.[1]

In recent decades, major advancements have transformed skull base surgery, leading to improved patient outcomes and quality of life.[2] This progress has been driven by technological innovations, a deeper understanding of anatomy, and enhanced multidisciplinary collaboration. Endoscopic techniques offer superior visualization, allowing surgeons to navigate complex anatomical structures with greater precision.[3-5] Furthermore, intraoperative imaging modalities such as 3D ultrasound and magnetic resonance imaging (MRI) improve surgical accuracy, reducing complications and enhancing patient safety. Navigation systems and indocyanine green angiography have also contributed to greater surgical precision, further optimizing outcomes.[6-8]

The incorporation of personalized medicine is set to further advance skull base surgery. Developments in imaging, genomics, and artificial intelligence (AI) are enabling more individualized treatment approaches. AI-driven image analysis can improve preoperative planning by predicting tumor behavior and optimizing surgical pathways. Intraoperative AI-assisted decision-making may soon facilitate real-time surgical adjustments, enhancing precision and shortening the learning curve for complex procedures.[9-11] Customizing surgical techniques based on a patient's specific anatomical and pathological characteristics is no longer a distant possibility but an emerging reality.

Robotic-assisted surgery represents a growing advancement in skull base procedures, extending the capabilities of minimally invasive techniques and enhancing dexterity in deep, previously inaccessible regions. As robotic systems become more advanced, their role in skull base surgery is expected to expand further. If newly developed robotic systems can overcome challenges such as maneuverability constraints in narrow spaces like the nasal cavity, lack of tactile feedback, and integration with imaging and navigation systems, their use in this field will likely increase.[12,13]

The adoption of advanced 3D modeling technologies is transforming preoperative planning and training in skull base surgery. By collaborating with neuroradiologists and engineers, surgeons can generate anatomically precise models derived from computed tomography and MRI images, enabling them to simulate procedures and refine surgical techniques before operating.[14] Additionally, virtual reality simulations provide immersive training experiences that enhance surgical education and improve overall procedural quality.[6,15]

Multidisciplinary collaboration remains fundamental to skull base surgery. The combined expertise of otolaryngologists, neurosurgeons, radiologists, and oncologists is essential for providing comprehensive patient care. As subspecialization continues to grow, fostering effective teamwork and shared decision-making will be crucial to optimizing patient outcomes.[1]

Looking ahead, the future of skull base surgery will likely be shaped by ongoing technological advancements, personalized surgical strategies, and greater AI integration. While technology expands surgical capabilities, the core principles of skull base surgery remain unchanged: a deep understanding of human anatomy, precise surgical technique, and the ability to navigate complex procedures with skill, evidence-based practice, and multidisciplinary collaboration.

As we adopt these innovations, it is essential to ensure that technological reliance does not diminish the fundamental surgical expertise that defines the field. No algorithm can replicate a surgeon's intuition, nuanced intraoperative decision-making, or the patient-centered approach that ensures compassionate care. The successful integration of these advancements will depend not only

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on their technological refinement but also on how surgeons adapt and apply them in clinical practice.

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REFERENCES

1. Vural A. New horizons and current developments in skull base surgery. In: Papila I, ed. New horizons in otolaryngology and head and neck surgery. İstanbul: İÜC Yayınevi; 2023;69-73 (Turkish). [CrossRef]
2. Kikuchi M, Nakagawa T. Recent progress in endoscopic skull base surgery: Functional preservation and multiportal approaches. *Auris Nasus Larynx*. 2023;50:32-39. [CrossRef]
3. Grammatica A, Schreiber A, Vural A, et al. Application of a 3D 4K exoscopic system to head and neck reconstruction: a feasibility study. *Eur J Plast Surg*. 2019;42:611-614. [CrossRef]
4. Zaidi HA, Zehri A, Smith TR, Nakaji P, Laws ER Jr. Efficacy of three-dimensional endoscopy for ventral skull base pathology: a systematic review of the literature. *World Neurosurg*. 2016;86:419-431. [CrossRef]
5. Cappabianca P, Doglietto F, Gentili F, Nicolai P. Endoscopic skull base surgery: where on the parabola? *J Neurosurg Sci*. 2016;60:438-440. [CrossRef]
6. Tzelnick S, Rampinelli V, Sahovaler A, et al. Skull-base surgery-a narrative review on current approaches and future developments in surgical navigation. *J Clin Med*. 2023;12:2706. [CrossRef]
7. Castelnuovo P, Battaglia P, Bignami M, et al. Endoscopic transnasal resection of anterior skull base malignancy with a novel 3D endoscope and neuronavigation. *Acta Otorhinolaryngol Ital*. 2012;32:189-191. [CrossRef]
8. Gaudioso P, Contro G, Taboni S, et al. Intraoperative surgical navigation as a precision medicine tool in sinonasal and craniofacial oncologic surgery. *Oral Oncol*. 2024;157:106979. [CrossRef]
9. Mattavelli D, Fiorentino A, Tengattini F, et al. Additive manufacturing for personalized skull base reconstruction in endoscopic transclival surgery: a proof-of-concept study. *World Neurosurg*. 2021;155:e439-e452. [CrossRef]
10. Lee LIT, Kanthasamy S, Ayyalaraju RS, Ganatra R. The current state of artificial intelligence in medical imaging and nuclear medicine. *BJR Open*. 2019;1:20190037. [CrossRef]
11. Korkmaz S. Artificial Intelligence in healthcare: a revolutionary ally or an ethical dilemma?. *Balkan Med J*. 2024;41:87-88. [CrossRef]
12. Vural A, Negm H, Vicini C. Robotic surgery of skull base. In: Cingi C, Bayar Muluk N, (eds). All around the nose. Springer, Cham. 2020. [CrossRef]
13. Bolzoni Villaret A, Doglietto F, Carobbio A, et al. Robotic transnasal endoscopic skull base surgery: systematic review of the literature and report of a novel prototype for a hybrid system (brescia endoscope assistant robotic holder). *World Neurosurg*. 2017;105:875-883. [CrossRef]
14. Langdon C, Hinojosa-Bernal J, Munuera J, et al. 3D printing as surgical planning and training in pediatric endoscopic skull base surgery - systematic review and practical example. *Int J Pediatr Otorhinolaryngol*. 2023;168:111543. [CrossRef]
15. James J, Irace AL, Gudis DA, Overdevest JB. Simulation training in endoscopic skull base surgery: a scoping review. *World J Otorhinolaryngol Head Neck Surg*. 2022;8:73-81. [CrossRef]