14 Robotic Surgery of the Skull Base

Michael E. Kupferman and Ehab Hanna

14.1 Introduction

In the past several years, transnasal endoscopic approaches have been increasingly used for surgical access and treatment of neoplastic and benign lesions of the anterior and central skull base. Endoscopic surgery is used with increasing frequency for surgical resection of tumors of the sinonasal tract, such as inverted papilloma, angiofibroma, osteomas, and other benign fibro-osseous lesions, and in selected patients with malignant sinonasal tumors [1–5]. Endoscopic approaches are also becoming popular for transsphenoidal access to the sella turcica and are considered by many centers as the preferred surgical approach for treatment of pituitary adenomas [6–9]. More recently, there has been an emerging trend to expand the use of transnasal endoscopic approaches in the surgical treatment of suprasellar, petroclival, infratemporal, and other intracranial skull base tumors [10–14].

The increasing popularity of these endoscopic skull base approaches may be attributed to a larger trend toward more "minimally invasive" techniques across all surgical disciplines. The main advantage of transnasal endoscopic skull base approaches is providing more direct access to the anterior and central skull base while avoiding craniofacial incisions and extensive bone removal commonly used in open surgical approaches. Also, the wider angle of vision and angled lenses increases the range of the endoscopic visual surgical field compared with the "line of sight" visual field gained by surgical loupes or microscopes.

One major disadvantage of transnasal endoscopic approaches is the inability to provide a truly watertight dural closure and reconstruction. Current techniques of endoscopic skull base reconstruction, such as tissue grafts, mucosal flaps, and tissue sealants, provide adequate reconstruction of limited skull base defects, such as a post-traumatic cerebrospinal fluid leak [15, 16]. However, for larger dural defects, these endoscopic techniques have higher cerebrospinal fluid leak rates compared with traditional reconstructive techniques used in open surgery, such as the vascularized pericranial flap [10].

While the application of robotic technology to surgery has rapidly expanded over the last 5 years, one of the least studied but fertile areas for application of surgical robotics in the head and neck is for minimally invasive skull base surgery. Certain advantages that these novel systems offer are the ability to perform bimanual surgery in confined cavities with instrumentation that exceeds the capabilities of the human hand, providing the surgeon with a 3D view of the surgical field. Significant advances in surgical robotics have been made [17], although a role for robotic-based applications in skull base surgery has not been completely defined.

M.E. Kupferman, MD (✉) • E. Hanna, MD
Department of Head and Neck Surgery,
MD Anderson Cancer Center, 1515 Holcombe Blvd,
Unit 1445, Houston, TX 77030, USA
e-mail: mekupfer@mdanderson.org

Z. Gil et al. (eds.), *Atlas of Head and Neck Robotic Surgery*, DOI 10.1007/978-3-319-49578-1_14

14.2 Techniques

14.2.1 Approach to the Anterior Cranial Fossa

The feasibility of using the surgical robot to access the anterior and central skull base has been demonstrated in a cadaver model [18]. Caldwell-Luc incisions and wide anterior maxillary antrostomies followed by wide middle meatal antrostomies are the entry points for the surgical arms (Fig. 14.1a). Sufficient access can be obtained without compromising the infraorbital nerves (Fig. 14.1b), and a posterior septectomy provides a common bilateral surgical field. The robotic endoscope is then placed into the patient's nare and the right and left surgical arms introduced through the respective maxillary sinuses (Fig. 14.1c). Anterior and posterior ethmoidectomies are performed, and sphenoidotomies provide exposure to the planum sphenoidale, sella turcica, and parasellar regions (Fig. 14.2a, b). With current technology, this would be best performed using traditional transnasal endoscopic techniques prior to docking the robotic patient cart. In addition, current robotic instrumentation does not include a drill, although prototypes are under preclinical investigation. Therefore, removal of the anterior skull base bone would likewise be best performed without robotic assistance. Access to the anterior cranial fossa is provided by sharp dissection of the anterior skull base and incision of the dura (Fig. 14.3a–c). The dual robotic arms can be used for primary repair of the dura [19]. This approach provides excellent access to the anterior and central skull base, including the cribriform plate, fovea ethmoidalis, medial orbits, planum sphenoidale, nasopharynx, pterygopalatine fossa, and clivus. The most significant advantage of this approach is the ability to perform two-handed tremor-free endoscopic closure of dural defects. To date, this approach remains investigational in nature due to the lack of bone-cutting instrumentation, as discussed at the end of this chapter.

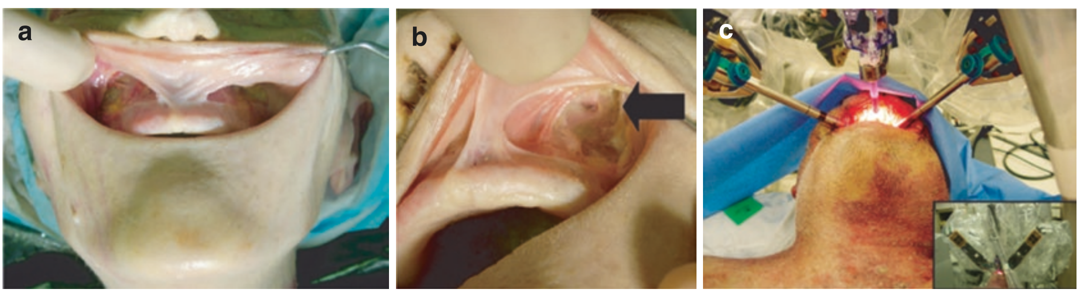

Fig. 14.1 (**a**) Sublabial incisions with bilateral exposure of the face of the maxilla. (**b**) Identification and preservation of the infraorbital nerve (*arrow*). (**c**) Docking of the camera (*C*) and the robotic arms via maxillary antrotomies

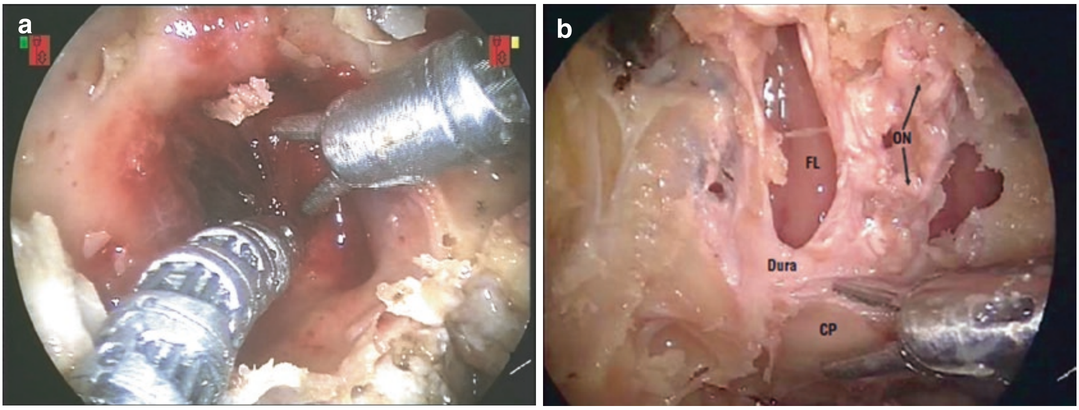

Fig. 14.2 (**a**) Dissection of the posterior wall of the sphenoid sinus. (**b**) The cribriform plate (CP) is removed bilaterally, and the cut edges of the olfactory nerves (ON) are shown; the dura is incised or resected to expose the inferior surface of the frontal lobes (FL) intracranially

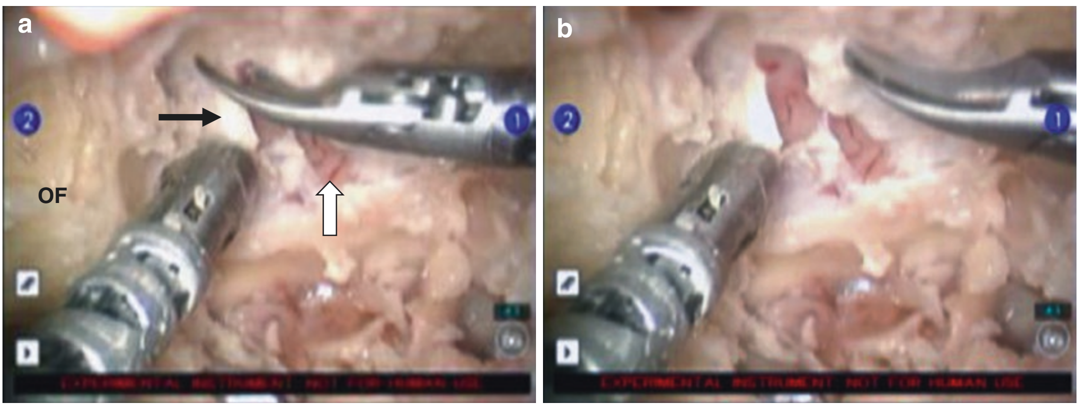

Fig. 14.3 (**a**) Resection of the cribriform plate (CP) and (**b**, **c**) incision of the dura (*black arrow*) with the robotic instrumentation after complete exposure of medial orbital walls (OF—orbital fat) and sphenoid sinus (S). The frontal lobe is visible (*white arrow*)

14.2.2 Approach to the Pituitary Fossa

While the transnasal endoscopic approach to the pituitary fossa has become a widely utilized technique for surgical resection [20, 21], robotic surgery in this anatomic location may provide unique advantages over the four-handed technique. The feasibility of a robotic approach to the pituitary fossa has been described by the authors and remains investigational [22].

Similar to the approach to the anterior cranial fossa, access involves creating bilateral maxillary antrostomies and docking the robotic arms and camera, as described above. An anterior sphenoidotomy is then performed and the sellar floor removed to expose the dura of the pituitary fossa (Fig. 14.4a, b). The dura is opened sharply with the robotic scissors to allow for exploration of the pituitary gland (Fig. 14.5a). Blunt and sharp dissection may be then performed to excise the pituitary gland after the optic chiasm and hypothalamus are exposed (Fig. 14.5b). Dissection of the lateral wall of the sphenoid sinus may also be performed with high-speed drills and fine rongeurs to access the cavernous sinus. Using this technique access to the central skull base, including the planum sphenoidale, the pituitary gland, cavernous carotid, mammillary bodies, and optic chiasm, can be achieved (Fig. 14.5c).

A transcervical approach to the skull base in canine and cadaver models has been previously described. Access to the sphenoid, clivus, sella, and suprasellar anterior fossa can be obtained by placing a 30 degree robotic endoscope transorally and placing the right and left robotic arms through the lateral pharyngeal walls via a transcervical technique, posterior to the submandibular gland [23].

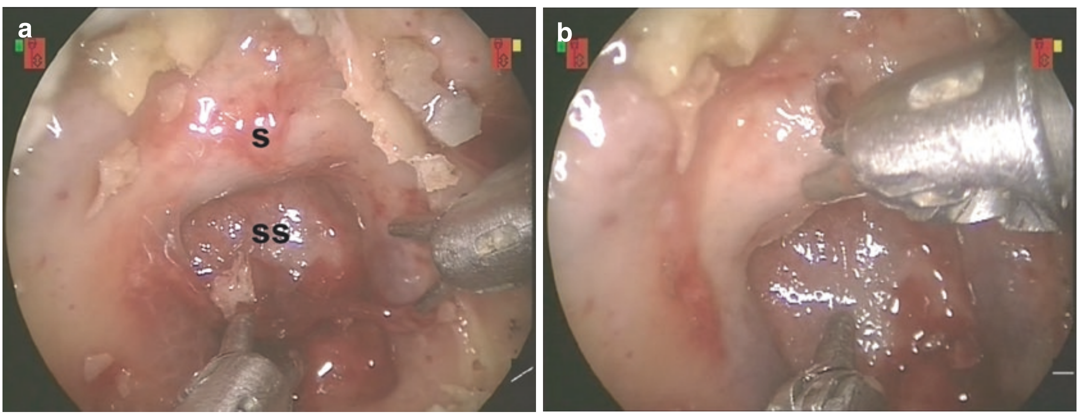

Fig. 14.4 (**a**) Exposure of the anterior face of the sella (*s* sella, *ss* sphenoid sinus). (**c**) Entry into the pituitary fossa

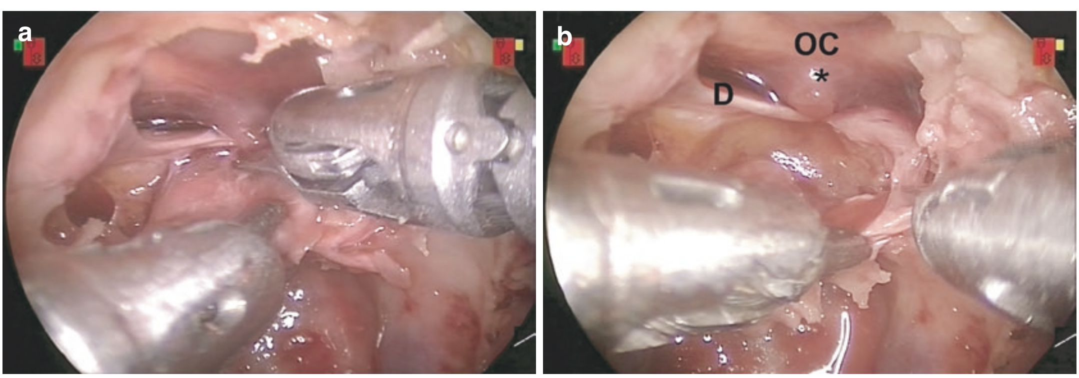

Fig. 14.5 (**a**) Resection of the pituitary gland. (**b**) Transected pituitary stalk and exposure of the optic chiasm (* pituitary stalk, *D* diaphragma sellae, *OC* optic chiasm). (**c**) Visualization of the mammillary bodies (MB)

14.2.3 Approach to the Nasopharynx

Robotic surgery of the nasopharynx is perhaps the only anatomic site of the skull base that is most amenable to surgical dissection with current iterations of surgical robotics. The feasibility of robotic resection of nasopharyngeal lesions in a cadaver was first described in 2008 [24], and subsequent case reports of surgical management of nasopharyngeal cancers have been published in the literature [25].

A Dingman retractor is utilized to expose the oral cavity, and the soft palate is divided under direct visualization—lateral retraction of the divided palate is achieved with Vicryl suture (Fig. 14.6a). The da Vinci robot is then docked at the head of the bed, and the robotic arms are positioned into the oral cavity. Typically, a 30 degree endoscope providing a superiorly oriented view of the oropharynx and nasopharynx is utilized. Using the Maryland forceps and the spatula cautery, the nasopharynx soft tissue may then be progressively degloved (Fig. 14.6b) between the carotid arteries and Eustachian tubes (Fig. 14.6c) laterally and the skull base and prevertebral musculature posteriorly. Once the tumor is resected, the palate is closed in three layers with absorbable suture. The advantage of this technique is that it allows for en bloc excision of nasopharyngeal lesions and may offer the advantage of decreased morbidity compared to either re-irradiation or open surgical approaches for recurrent nasopharyngeal carcinoma. Further study is necessary to delineate the optimal surgical indications.

14.2.4 Approach to the Infratemporal Fossa

Both preclinical studies and case reports addressing the infratemporal fossa and parapharyngeal space via robotic approaches have been described [26, 27]. Dissection is performed through the lateral pharyngeal wall to access the parapharyngeal space. Using the 30 degree endoscope directed superiorly, the parapharyngeal space can be carefully explored to identify the neurovascular contents—jugular vein, internal carotid, and CN IX, X, XI, and XII. To gain exposure superiorly and laterally (to the infratemporal fossa), the styloid musculature can be resected and pterygoid muscles partially released. This approach may be best suited for well-circumscribed benign lesions.

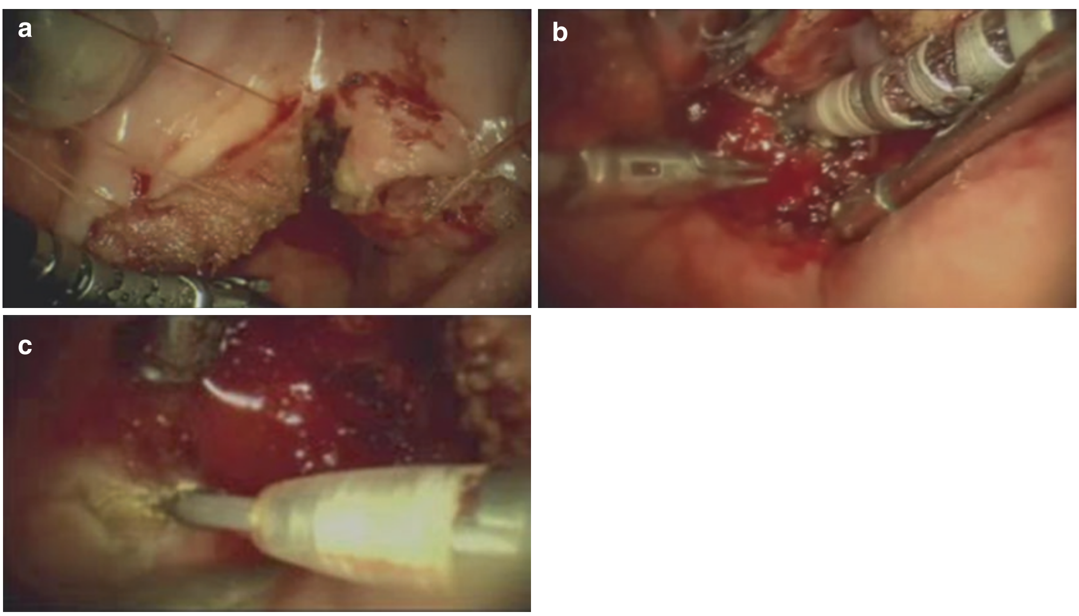

Fig. 14.6 (**a**) Exposure of the nasopharynx is achieved with a palatal split incision. (**b**) Incisions in the superior and inferior aspects of the nasopharynx commence the posterior dissection. (**c**) Incision through the Eustachian tube commences the lateral dissection

14.2.5 Skull Base Reconstruction

Perhaps the most significant limitation of current transnasal endoscopic techniques is the inability to reconstruct dural defects with a sutured watertight dural closure. Options for repair of the skull base include free mucosal grafts, fascia lata grafts, pedicled mucosal grafts, and biological materials [15, 16, 28–30]. While each has advantages and disadvantages, only the pedicled mucoperiosteal grafts are vascularized [31], a necessary component of any reconstruction in patients undergoing postoperative irradiation or in previously irradiated patients. One of the major drawbacks of the endoscopic approach is the inability to perform a suture-based reconstruction of the dura using currently available technology, an approach that is easily undertaken with a pericranial flap through the transcranial approach. We previously reported the feasibility of an endonasal robotic surgical dural reconstruction to address this problem in skull base surgery.

Repair of the skull base defect can be performed robotically with two distinct techniques. First, repair of the dura may be primarily reconstructed with both continuous and interrupted suture technique (Fig. 14.7a). Additionally, harvested sinonasal mucoperiosteal graft can be sutured into dural defects with both running and interrupted suture techniques (Fig. 14.7b). While these techniques have been demonstrated in cadaver models, their application in human use has yet to be realized.

A balanced analysis of where robotic surgery may lie on the spectrum of surgical modalities suggests that robotic-assisted skull base surgery offers unique advantages that are lacking in either microscopic or transnasal endoscopic techniques. These can be divided in four major areas: optical, ergonomic, dissection, and reconstructive. The following is a discussion of how endoscopic robotic surgery can overcome some of the limitations of these other techniques and where robotic surgery has limitations.

14.2.5.1 Optical Limitations

The two-dimensional visualization provided by single-channel optical systems in current endoscopes lacks the depth perception of 3D vision provided by the binocular optical systems used in standard microsurgery. During endoscopic surgery, depth perception relies more on tactile than on visual cues. Visual depth perception is particularly important when operating on critical intracranial neurovascular structures, especially when working in a deep and limited space. The 5 mm robotic endoscope has a dual-channel optical system coupled with a dual charge-coupled device, which allows for 3D visualization of the surgical field at the surgeon's console. This "binocular endoscope" allows the surgeon to have the combined benefit of a wider angle of vision and the depth perception of 3D visualization.

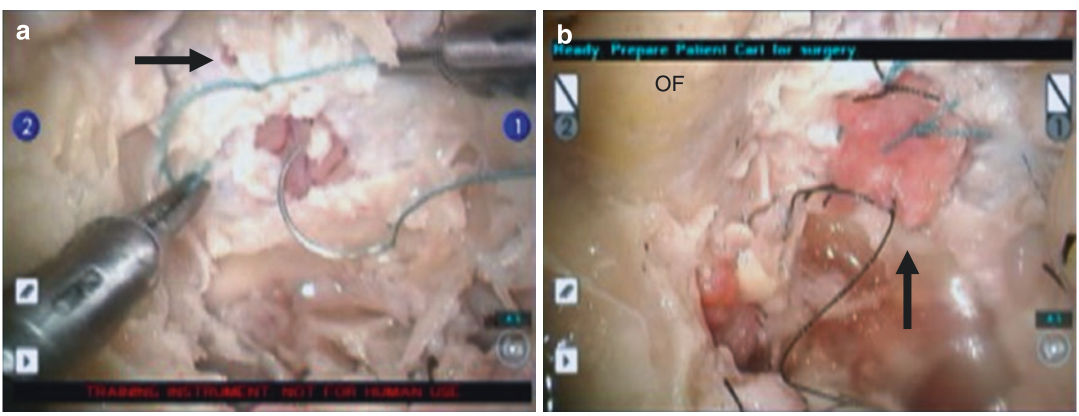

Fig. 14.7 (**a**) Primary repair of a dural defect (*arrow*) with polyglactin suture (Ethicon). (**b**) Repair of a large dural defect with a mucosal graft (*white arrow*)

14.2.5.2 Ergonomic Limitations

Current endoscopic techniques have several ergonomic limitations. Bimanual surgery is only feasible if the endoscope is held by an assistant or a mechanical holder. A surgical assistant is preferred because of the constant need to adjust the position (depth and angle) of the endoscope during endoscopic surgery. This not only limits the direct control of the endoscope by the primary surgeon but also requires the assistance of a relatively experienced endoscopic surgeon who can seamlessly follow the primary surgeon in every step of the operation.

Also, both surgeons have to work within the confined space provided by the nostrils, which in some cases limits ergonomic freedom. In addition, as the surgical field gets deeper, longer instruments are needed, and, with lack of proper arm support, precision may be limited by fine tremor, especially when using fine instrumentation for delicate dissection of critical neurovascular structures. The robotic system has four arms, all of which are controlled by the primary surgeon sitting at the console. One arm, the camera port, holds the endoscope; two arms hold right- and left-hand instruments; and a fourth "spare" arm may be dedicated for retraction or a third instrument. This allows the primary surgeon simultaneous direct control of the endoscope and the instrumentation, an advantage not feasible with non-robotic endoscopic techniques. Another advantage of the "endowrist" technology used in the da Vinci robotic instrumentation is its ability to provide movement at the instrument tip with 7° of freedom and 90° of articulation and motion scaling. This allows the surgeon, who sits comfortably at the console with an adjustable arm, support to perform precise tremor-free movement in a deep and confined space, with working angles usually not achievable with non-robotic instruments.

14.2.5.3 Dissection Limitations

In its current iteration, the da Vinci robotic system is designed exclusively for soft tissue surgery, while the paranasal sinuses and skull base are bony anatomic structures. Access to tumors in these domains requires bone-cutting instrumentation, including rongeurs, osteotomes, and drills. The exquisitely tuned internal pulley system within the robotic arms is not engineered for the stress forces that bony dissection requires. In our experience, use of the robotic dissecting instruments led to rapid deterioration in the functionality and life-span of the equipment (unpublished data). Moreover, prototype bone-cutting instrumentation, including robotically controlled drills and rongeurs, has yet to be commercialized (unpublished data). While an entirely endonasal approach has been developed by the authors, its broad implementation has yet to be undertaken (unpublished data). Further optimization of the robotic instrumentation will be required before skull base surgery can be effectively performed with the novel technology.

14.2.5.4 Reconstructive Limitations

The most significant limitation of current transnasal endoscopic techniques is the inability to suture and provide watertight dural closure or reconstruction of dural defects. Endoscopic repair of dural defects relies on nonvascularized fat, mucosal or allogeneic grafts, or vascularized septal or nasal rotational mucosal flaps. These reconstructions are then covered with fibrin sealants and supported by either absorbable or non-absorbable packing. While these methods may provide adequate reconstruction of minor dural tears or defects, their ability to provide safe and reliable reconstruction of larger dural defects remains to be seen. Preliminary results suggest that these methods have a higher cerebrospinal fluid leak rate compared with the more standard dural reconstruction using pedicled (axial) flaps, such as the pericranial flap or microvascular free flaps. Adequate and reliable dural reconstruction is critical in minimizing the morbidity of skull base resections, particularly in patients who received or will undergo high-dose radiation therapy. As described above, robotic-assisted surgery allows for successful and precise endoscopic suturing of the dura. This may drastically impact the utility and safety of endoscopic surgery of intracranial intradural lesions of the skull base.

Conclusion

While still in the developmental stages, robotic applications to skull base surgery are forthcoming. Transantral robotic surgery provides stereoscopic endoscopic access to the anterior skull base and pituitary fossa and allows for two-handed endoscopic manipulation and reconstruction. Traditional suture and reconstructive techniques can be implemented in this confined surgical site with the use of robotic technology. These advantages may expand the indications of minimally invasive endoscopic approaches to the skull base. Future development and refinement of endonasal robotic instrumentation is critical before applying these techniques in the clinical setting.

References

1. Hanna E, DeMonte F, Ibrahim S, Roberts D, Levine N, Kupferman M. Endoscopic resection of sinonasal cancers with and without craniotomy: oncologic results. Arch Otolaryngol Head Neck Surg. 2009;135(12):1219–24.
2. Lund V, Howard DJ, Wei WI. Endoscopic resection of malignant tumors of the nose and sinuses. Am J Rhinol. 2007;21(1):89–94.
3. Nicolai P, Battaglia P, Bignami M, et al. Endoscopic surgery for malignant tumors of the sinonasal tract and adjacent skull base: a 10-year experience. Am J Rhinol. 2008;22(3):308–16.
4. Suriano M, De Vincentiis M, Colli A, Benfari G, Mascelli A, Gallo A. Endoscopic treatment of esthesioneuroblastoma: a minimally invasive approach combined with radiation therapy. Otolaryngol Head Neck Surg. 2007;136(1):104–7.
5. Shipchandler TZ, Batra PS, Citardi MJ, Bolger WE, Lanza DC. Outcomes for endoscopic resection of sinonasal squamous cell carcinoma. Laryngoscope. 2005;115(11):1983–7.
6. Anand VK, Schwartz TH, Hiltzik DH, Kacker A. Endoscopic transphenoidal pituitary surgery with real-time intraoperative magnetic resonance imaging. Am J Rhinol. 2006;20(4):401–5.
7. Schwartz TH, Stieg PE, Anand VK. Endoscopic transsphenoidal pituitary surgery with intraoperative magnetic resonance imaging. Neurosurgery. 2006;58(1 Suppl):ONS44–ONS51; discussion ONS44–51.
8. Sethi DS, Leong JL. Endoscopic pituitary surgery. Otolaryngol Clin N Am 2006;39(3):563–583, x.
9. Teo C. Application of endoscopy to the surgical management of craniopharyngiomas. Childs Nerv Syst. 2005;21(8–9):696–700.
10. Kassam A, Carrau RL, Snyderman CH, Gardner P, Mintz A. Evolution of reconstructive techniques following endoscopic expanded endonasal approaches. Neurosurg Focus. 2005;19(1):E8.
11. Kassam A, Snyderman CH, Mintz A, Gardner P, Carrau RL. Expanded endonasal approach: the rostrocaudal axis. Part I. Crista galli to the sella turcica. Neurosurg Focus. 2005;19(1):E3.
12. Kassam AB, Gardner P, Snyderman C, Mintz A, Carrau R. Expanded endonasal approach: fully endoscopic, completely transnasal approach to the middle third of the clivus, petrous bone, middle cranial fossa, and infratemporal fossa. Neurosurg Focus. 2005;19(1):E6.
13. Kassam AB, Snyderman C, Gardner P, Carrau R, Spiro R. The expanded endonasal approach: a fully endoscopic transnasal approach and resection of the odontoid process: technical case report. Neurosurgery 2005;57(1 Suppl):E213; discussion E213
14. Solari D, Magro F, Cappabianca P, et al. Anatomical study of the pterygopalatine fossa using an endoscopic endonasal approach: spatial relations and distances between surgical landmarks. J Neurosurg. 2007;106(1):157–63.
15. Basu D, Haughey BH, Hartman JM. Determinants of success in endoscopic cerebrospinal fluid leak repair. Otolaryngol Head Neck Surg. 2006;135(5):769–73.
16. Locatelli D, Rampa F, Acchiardi I, Bignami M, De Bernardi F, Castelnuovo P. Endoscopic endonasal approaches for repair of cerebrospinal fluid leaks: nine-year experience. Neurosurgery 2006;58(4 Suppl 2):ONS-246–ONS-256; discussiom ONS-256–247.
17. Weinstein GS, O'Malley Jr BW, Snyder W, Hockstein NG. Transoral robotic surgery: supraglottic partial laryngectomy. Ann Otol Rhinol Laryngol. 2007;116(1):19–23.
18. Hanna EY, Holsinger C, DeMonte F, Kupferman M. Robotic endoscopic surgery of the skull base: a novel surgical approach. Arch Otolaryngol Head Neck Surg. 2007;133(12):1209–14.
19. Kupferman ME, Demonte F, Levine N, Hanna E. Feasibility of a robotic surgical approach to reconstruct the skull base. Skull Base: Off J N Am Skull Base Soc [et al]. 2011;21(2):79–82.
20. Cappabianca P, Cavallo LM, de Divitiis O, Solari D, Esposito F, Colao A. Endoscopic pituitary surgery. Pituitary. 2008;11(4):385–90.
21. Liu JK, Weiss MH, Couldwell WT. Surgical approaches to pituitary tumors. Neurosurg Clin N Am. 2003;14(1):93–107.
22. Kupferman M, Demonte F, Holsinger FC, Hanna E. Transantral robotic access to the pituitary gland. Otolaryngol Head Neck Surg. 2009;141(3):413–5.
23. O'Malley Jr BW, Weinstein GS. Robotic anterior and midline skull base surgery: preclinical investigations. Int J Radiat Oncol Biol Phys. 2007;69(2 Suppl):S125–8.

24. Ozer E, Waltonen J. Transoral robotic nasopharyngectomy: a novel approach for nasopharyngeal lesions. Laryngoscope. 2008;118(9):1613–6.
25. Wei WI, Ho WK. Transoral robotic resection of recurrent nasopharyngeal carcinoma. Laryngoscope. 2010;120(10):2011–4.
26. McCool RR, Warren FM, Wiggins 3rd RH, Hunt JP. Robotic surgery of the infratemporal fossa utilizing novel suprahyoid port. Laryngoscope. 2010;120(9):1738–43.
27. O'Malley Jr BW, Weinstein GS. Robotic skull base surgery: preclinical investigations to human clinical application. Arch Otolaryngol Head Neck Surg. 2007;133(12):1215–9.
28. Hadad G, Bassagasteguy L, Carrau RL, et al. A novel reconstructive technique after endoscopic expanded endonasal approaches: vascular pedicle nasoseptal flap. Laryngoscope. 2006;116(10):1882–6.
29. Leong JL, Citardi MJ, Batra PS. Reconstruction of skull base defects after minimally invasive endoscopic resection of anterior skull base neoplasms. Am J Rhinol. 2006;20(5):476–82.
30. Mehta RP, Cueva RA, Brown JD, et al. What's new in skull base medicine and surgery? Skull Base Committee Report. Otolaryngol Head Neck Surg. 2006;135(4):620–30.
31. Kassam ABMD, Carrau RLMD, Snyderman CHMD, et al. Endoscopic reconstruction of the cranial base using a pedicled nasoseptal flap. Neurosurgery 2008;63(1) Operative Neurosurgery Supplement(1): ONS44–S53.