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Robotic Surgery of Skull Base

Alperen Vural, Hesham Negm, and Claudio Vicini

80.1 Introduction

Czech novelist Karel Čapek introduced the word "robot" to the English language in his science fiction play Rossum's Universal Robots (*Rossumovi Univerzální Roboti*) in 1920 [1]. A robot is an automated electromechanical device that is controlled by a computer program. Robotic systems in the field of medicine are remote performers that operate via the master-slave style [2]. The only Food and Drug Administration (FDA)-approved surgical robotic system, *the Da Vinci*® (Intuitive Surgical International, CA), is designed to imitate the surgeons' hand movements. The system consists of three major parts: the surgical console, the patient-side cart, and the vision cart. The surgical console is the remote part in which the surgeon operates seated by grasping the handpieces while viewing 3D images. The patient-side cart has three or four arms on which *EndoWrist*® instruments were installed that enable 7 degrees of motion performing surgeons' hand commands. An endoscope is attached on one of these arms. The vision cart is equipped with a high-definition 3D endoscope and image-processing equipment [2].

80.2 Robotics in Surgery

Robotic surgery has gained popularity in multiple different specialties such as urology, gastrointestinal surgery, cardiac surgery, obstetrics, and gynecology [3]. In 1983, the first robot-assisted surgical procedure was performed in the field of orthopedics with the use of "Arthrobot" [2]. Davies et al. [4] performed a robot-assisted transurethral resection of the prostate in 1989. A robot-assisted laparoscopic cholecystectomy was performed by Himpens et al. [5] in 1997. Moreover, Jacques Marescaux performed a telerobotic cholecystectomy to a patient in Strasbourg while sitting at the surgical console in New York City in 2001 [6]. With the improvements in technology, new robotic platforms are emerging for use in different surgical specialties, which will enable new varieties of procedures to be performed (Fig. 80.1) [2].

80.2.1 Robotics in Otorhinolaryngology

Although lagged behind the other surgical specialties, the use of robotics in otorhinolaryngology-head and neck surgery has recently gained a significant popularity [7]. In 1995, Brett et al. [8] described the automated micro drilling of stapes footplate, which was the first attempt of the use of robots in the field of otorhinolaryngology. Haus et al. [9] published an experimental study in which they had performed robotic submandibular resection, selective neck dissection, partial parotidectomy, and thymectomy on the porcine models. Studies by Hockstein, O'Malley, and Weinstein et al. revealed the usefulness of robotic surgery in the oropharynx, hypopharynx, and larynx [10–13]. They pioneered the emergence of transoral robotic surgery (TORS), and after these leading studies, an FDA approval for TORS was gained for the benign diseases and T1 and T2 malignancies of head and neck in 2009 [14]. Recently, robot-assisted surgery is being intensively investigated and performed in all fields of otorhinolaryngology from thyroidectomy to cochlear implant insertion and from obstructive sleep apnea to skull base surgery and to other subspecialties [15–18].

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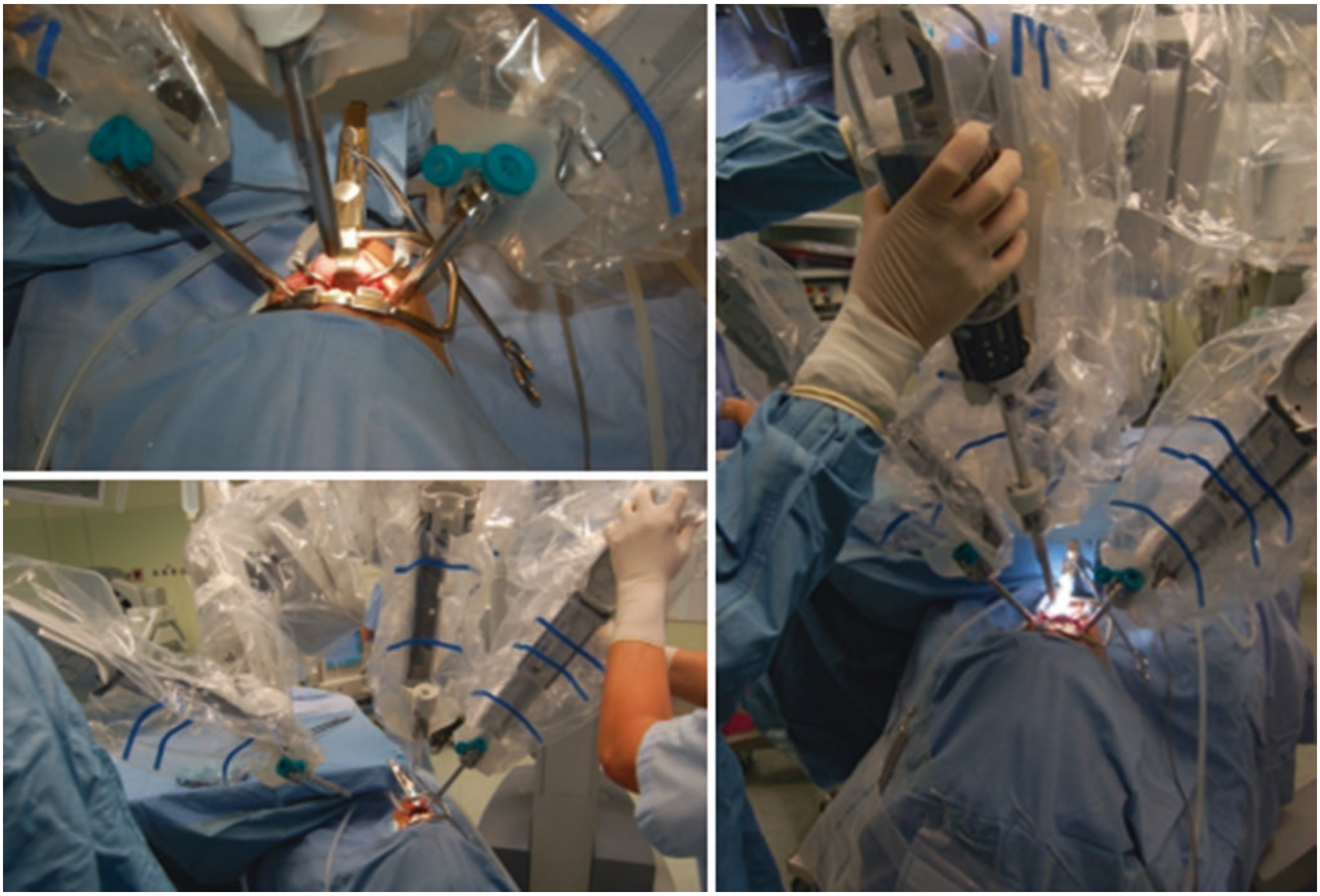

Fig. 80.1 Equipment of robotic surgery (Courtesy of Claudio Vicini MD)

80.3 Skull Base Surgery

Skull base surgery is challenging owing to its complex anatomy, deep-seated nature, and the neighboring vital structures [19]. Endonasal endoscopic approaches (EEA) to the skull base have become vigorously the preferred method in order to access areas previously reachable only through open approaches. The EEA is currently one of the main surgical techniques for transsphenoidal access to the sella and the favored approach by many surgeons for the treatment of pituitary adenomas [3, 20–23]. There has lately been remarkable extension of the use of EEAs through the suprasellar, infratemporal, petroclival, and other intracranial skull base tumors [24–27]. The endoscope enables working with a dynamic view of the area which is operated, making possible to change from a holistic perspective to a focused view of the target spot [28]. The major benefits of EEA are to provide a straightforward access to the anterior and central skull base, avoiding external incisions and extensive bone removal, and ability to preserve adjacent vital structures [3, 29]. Endoscopy has not only led to great improvements in the treatment of sinonasal and intracranial pathologies but also guided to a better perception of the anatomy of the sinonasal structures and beyond [28]. Better knowledge of the endoscopic nasal and skull base anatomy, operation with computer-aided navigation systems, use of powered instrumentations, and other technological advances have enabled surgeons to extend beyond the boundaries of the sinuses. The evolution in surgical techniques has made the endoscopic procedures suitable to access a variety of hidden areas from olfactory cleft to craniocervical junction. As the improvements proceed, the outcomes of these procedures have been evaluated, and with the light of the thriving technologies, incommensurate sides should be overtaken by novel approaches such as robotic surgery.

80.3.1 Robotics in Skull Base Surgery

Application of robotic surgery in the skull base appears as a logical approach. Although having several advantages, EEA has some major limitations when used in the skull

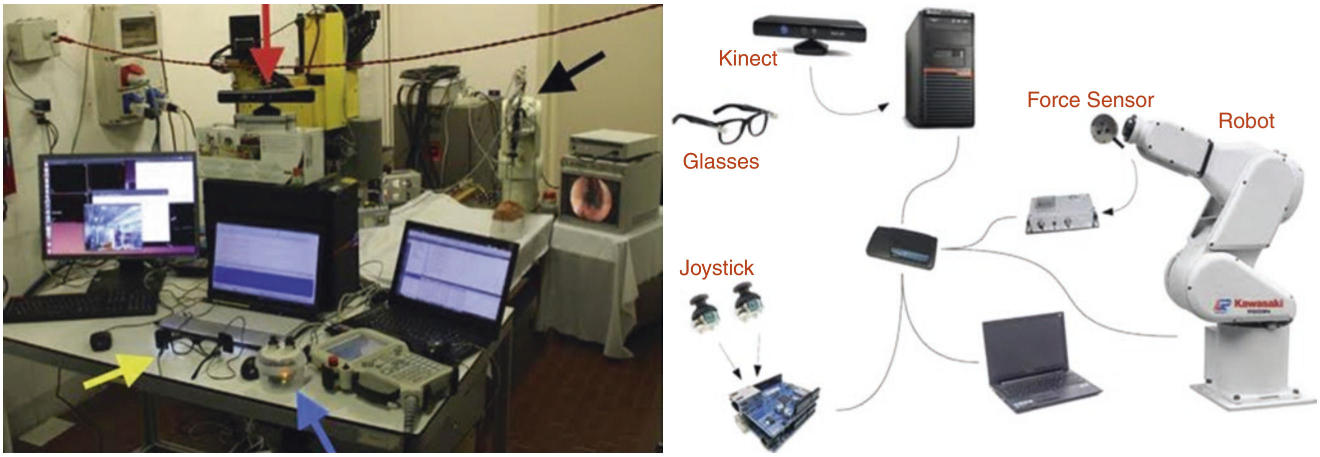

Fig. 80.2 Left: University of Brescia advanced robotic laboratory setup. Right: Brescia Endoscope-Assisted Robotic Holder (BEAR) System [32]

base which may be atoned by robotic surgery. First, the current endoscopes provide two-dimensional imaging that deteriorates visual depth perception which is crucial especially when working on deep-seated vital structures [3]. On the other hand, the robotic system provides high-definition three-dimensional view on surgeon's console that enables the surgeon to have a magnificent perception of depth in the surgical field. Second, endoscopic surgery of the skull base is ergonomically unfavorable and has some technical difficulties [3, 30]. One problem is that bimanual surgery is only available when working with the 4 hands technique, which means two surgeons have to work in a narrow space from two nostrils, one holding the endoscope and the other the surgical instruments. Furthermore, the use of relatively long rigid surgical instruments exaggerates intricate movements that might challenge the dissection of vital structures. These surgical instruments also lack wrists, which limits their dexterity. The robotic system has three or four arms, one holding the endoscope, all of which are controlled by the surgeon from the console. The robotic instruments have seven degrees of freedom and 90 degrees of articulation that enables the surgeon to reach areas that are otherwise hard to access in a tremor-free manner [3, 30]. Third concern regarding the EEA is the surgeon not being able to suture dural defects which would ensure impervious closure. Dural defects can be endoscopically managed, but endoscopic techniques have higher cerebrospinal fluid leak rates when the defect gets larger [31]. However, robotic surgery enables dural suturing that would make the reconstruction step much safer.

Recently, Bolzoni Villaret et al. [32] presented a novel prototype of a hybrid robotic system for endoscopic skull base surgery. They developed a system consisting of a robotic arm with a force sensor which can be controlled either with a joystick or marked glasses. They mentioned that the hybrid robot assistance system was promising and might be feasible in skull base surgery in the near future (Fig. 80.2).

Despite its abovementioned advantages, robotic surgery is not faultless. A major issue of concern in robotic surgery is its high cost [33]. Not only the initial investment budget it requires but also annual maintenance and disposable instrument costs could be stated among the deficiencies of the system. A second concern that needs to be addressed might be the time required to set up the system, which could be reduced via faster operative time achieved through its technical efficiency [3, 7]. Another issue is the lack of haptic feedback which means that the system does not let the surgeon feel the force applied to the surgical instruments. While some authors regard this issue as a crucial obstacle by stating that haptic feedback is of great importance for prosperous surgical performance [3, 7, 33–35], others do not consider it as a major limitation, claiming that it could be overcome by practice and experience [36, 37]. Above all, the robotic system, constructed mainly for soft tissue surgeries, may not be absolutely suitable for the anatomic structure of the paranasal sinuses and skull base as they are mostly bony areas [38]. Nevertheless, this restriction may be minimized with the advancements in the technology enabling the robotic arms to work on bony structures [39] even with navigational systems. In terms of accessibility, the robotic system also has some limitations besides its superior aspects. Having a narrow anatomy, the nasal corridor may limit the fitting and free motion of the endoscope and robot arms. Hence, studies have been conducted to evaluate methods of assessment of the skull base using different entry sites [3].

80.3.2 Robotic Surgical Techniques

80.3.2.1 Approaches to Sella

Several ways of approach to the sellar region have been described up to now; the most commonly used ones being the sublabial microscope-assisted technique and the transnasal endoscopic surgery [3, 40]. Many authors have detailed robot-assisted approaches to reach the sella [16, 41–45]. In the method described by Hanna et al. [31], the arm holding the endoscope was docked through the nostril and two surgical arms were inserted from the pre-created maxillary anterior antrostomies. The authors were able to access the sella turcica, supra and parasellar regions, as well as the cribriform plate, nasopharynx, pterygopalatine fossa, and clivus. O'Malley and Weinstein [46] have conducted experimental studies on a cadaver and a live mongrel dog, and in the former, they have placed the robotic arm holding the endoscope from the oral cavity and the instrument holding arms from the cervical incisions behind the submandibular glands. They reported access to the nasopharynx, clivus, sphenoid rostrum, sella, and suprasellar structures. Another way of approach to the sellar region is recently described in a cadaver study in which the authors performed a complete transoral robotic surgery in order to reach the sella [47]. To do that, they incised the soft palate but not the hard and drilled the bone between the vomer and sphenoid corpus. They regard their technique as advantageous since it prevents complications related to transnasal approaches.

80.3.2.2 Approaches to Anterior Cranial Fossa

Anterior cranial fossa has also been a target of the studies investigating robotic skull base surgery. In the aforementioned study [31], the authors reached the anterior skull base as previously described and regarded that via the robotic surgery, they achieved a bimanual, tremor-free primary dural closure. In another experimental cadaver dissection study, access to the anterior skull base was performed by combined transmaxillary and transnasal approaches [34]. Drilling was performed without using the robot, and the authors concluded that the robotic instruments need to be redesigned in a more feasible and practical manner.

80.3.2.3 Approaches to Parapharyngeal Space and Infratemporal Fossa

Robotic surgery has also been utilized for the dissection of the parapharyngeal space and infratemporal fossa. O'Malley and Weinstein [48] investigated and described the approach to the parapharyngeal space and infratemporal fossa in two cadavers, a live canine model and a patient. In the cadaver, to approach the parapharyngeal space via the TORS, they incised the lateral of the anterior tonsillar pillar and then achieved to perform a dissection of the carotid artery, jugular vein, and cranial nerves IX, X, XI, and XII through their foramens in the bony skull base. They, however, maintained that although they managed to dissect these structures, the technique was not suitable for wide resections which would be needed when a malignant disease is existent. The robot not being suitable for bony dissection was also emphasized as a limitation in this dissection when intracranial accession is required. In a human patient with a well-circumscribed mass in the parapharyngeal region, they performed the resection via the TORS. McCool et al. [49] used four cadavers to dissect the parapharyngeal space. They placed two arms of the robot transorally, one holding the endoscope, and inserted the third arm that has an entry into the oropharynx via the vallecula transcervically. They emphasized that the suprahyoid port was effective to gain wide access to the infratemporal fossa. Another way of approach to the infratemporal fossa described in the literature is via transmaxillary [34]. The authors initially opened an anterior maxillary osteoplastic window followed by the removal of the medial and posterior maxillary walls. Thereafter, the robot is placed and the dissection of a. maxillaris, a. meningea media, lateral pterygoid, foramen rotundum, and foramen ovale was performed. Kim et al. [50] presented four and Arshad et al. [51] presented three cases with parapharyngeal neoplasms to which both groups applied TORS. Both commented that TORS is safe and feasible in the use of parapharyngeal pathologies.

80.3.2.4 Approaches to Nasopharynx

Access to the nasopharynx, clivus, and craniocervical junction has also been subject to research. Ozer and Waltonen [52] performed a TORS procedure on a cadaver in which they incised the soft palate and reached the nasopharynx with a 30-degree angled endoscope and completed the nasopharyngectomy as well as clival resection. They suggested that the exposure was satisfactory, but design of finer instruments specific for the area is needed. Dallan et al. [53] designed a cadaver study in which they performed nasopharyngectomies. In the first cadaver, they placed the endoscope transnasally and the robot arms transorally (combined approach), and in the other, all arms were inserted from the oral cavity. The second procedure required palatal split while the first did not. They concluded that the combined transnasal and transoral approach to the nasopharynx offered a significant advantage in terms of visualization. Furthermore, they regarded that combined approach might allow for a dissection in more superior parts (Figs. 80.3 and 80.4). Lee et al. [54] demonstrated the access to the craniocervical junction with the robot transorally and asserted that the transoral path is the most direct and effective path to decompress it. Besides the experimental ones, studies carried out with live subjects are also present. In a patient with recurrent nasopharyngeal carcinoma, a robot-assisted transoral surgery was performed with palatal split. The authors declared minimal morbidity and commented that the method is safe and could be applied in suitable cases [55]. Carrau et al. [56] described a combination of EEA and TORS approaches in two cases,

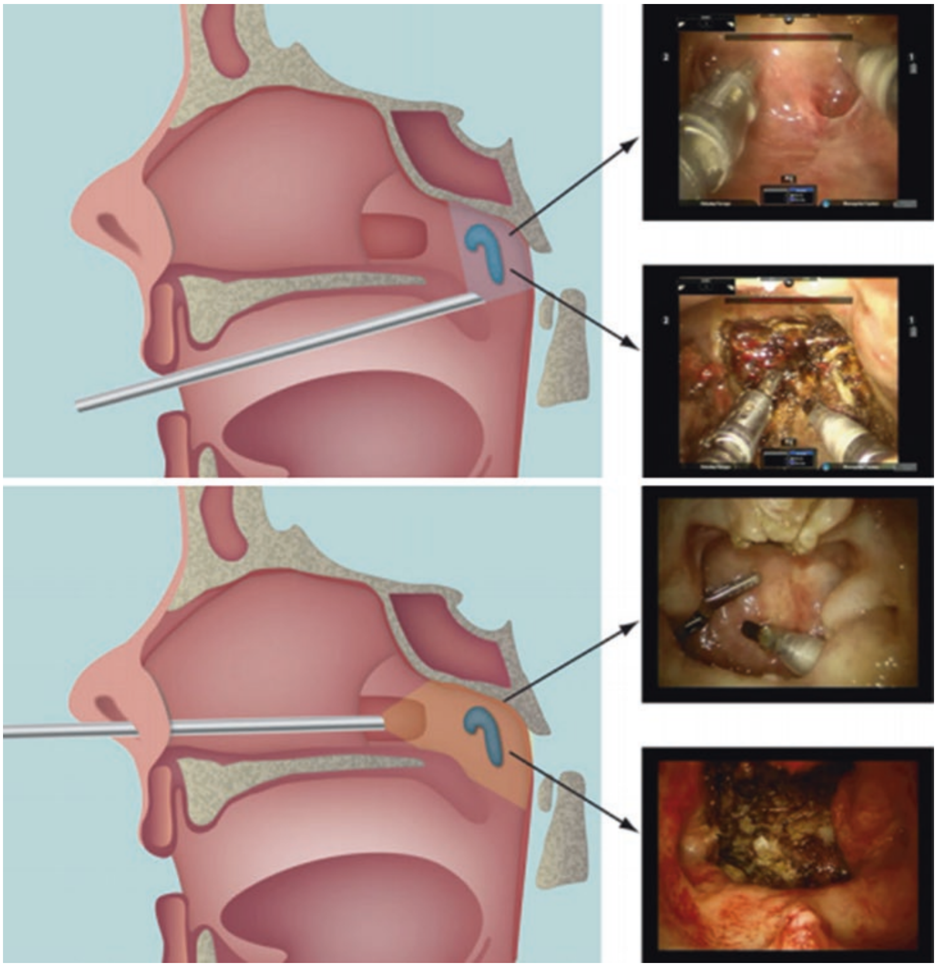

Fig. 80.3 Approach to the rhinopharynx by means of the transoral robotic surgery (TORS) (upper part of the figure) and by means of the combined transnasal-transoral procedure (CTTP) (lower part of the figure) (Courtesy of Claudio Vicini MD)

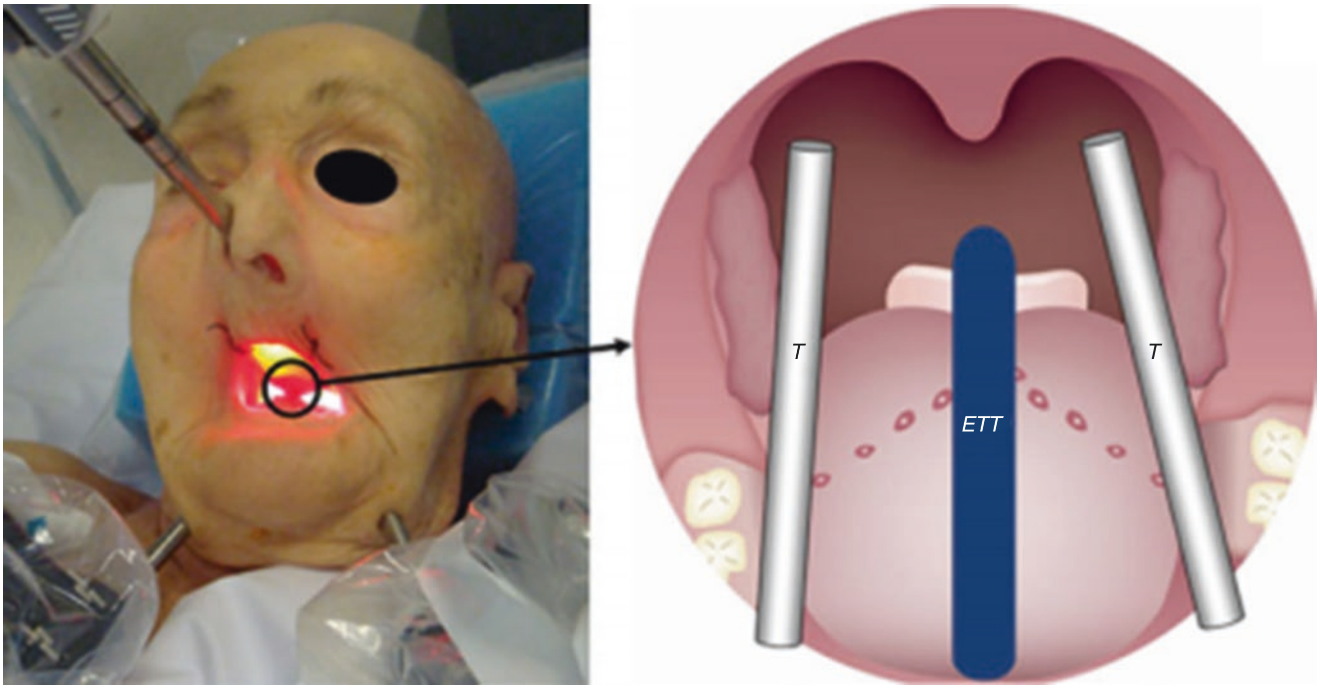

Fig. 80.4 Transnasal - transcervical robotic surgery (Courtesy of Claudio Vicini MD)

one having a nasopharyngeal adenoid cystic carcinoma and the other, a cordoma, involving middle-posterior skull base with an extension to craniocervical junction. The approach, as the authors mention, gives opportunity to achieve a wide oncologic resection with an exposure to posterior skull base, nasopharynx, and infratemporal fossa. They criticized that the TORS is limited in extending under the carotid bifurcation and lacking a drill for bony work, which prevents bony resection if required. The latter limitation, however, can be overcome by EEA. The studies show that robot-assisted resection of the nasopharynx, clivus, and craniocervical junction can be performed via transoral placement of the robotic arms.

80.4 Conclusion

In the treatment of skull base pathologies, the surgeon should compare the pros and cons of robot-assisted surgery with traditional approaches [57]. In this complex anatomical site, the optimal surgical technique should present the advantage of 3D vision, two-handed surgical dissection and the ability to make bony dissection, if possible, guided by a navigation system [31, 57]. Finally, we think that the future for the robotic surgery in skull base is up-and-coming. As this technique is relatively recent as compared to its counterparts, further research is required to compensate for its deficiencies and optimize the outcomes gained via this exciting technology.

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