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Robot-Assisted Surgery Around the Nose

Ayse Pelin Gör Yiğider and Fatma Tülin Kayhan

59.1 Introduction

Endonasal approaches to surgery in sinonasal regions have developed dramatically over the last 30 years. The nose, sinuses, and neighboring anatomical regions were once considered by otorhinolaryngologists as deep, dark, and hard-to-reach areas. Owing to improvements in endonasal endoscopic approaches and technologies, as well as in computerized tomography, these regions have now been fully exposed and mastered. Establishing the correct pathophysiology is important for diagnosis and treatment. Technological improvements have allowed for the development of more effective, easier-to-apply, and less invasive surgical modalities. For example, improvements in endonasal endoscopy have allowed us to understand the physiopathology of inflammatory conditions, such as rhinosinusitis, and have precipitated a change in approach to such diseases, finally resulting in the development of functional endoscopic sinus surgery. Recently, advanced endoscopic surgical techniques have emerged for orbital and cerebrospinal fluid (CSF) fistula repair. Endoscopic navigation is also considered to be a highly facilitative technology. Both malignant and benign lesions in the sinonasal region have been treated successfully using newly developed instruments. Recently, the skull base, infratemporal fossa, and petrous apex have all been managed endoscopically.

Endonasal endoscopic sinus surgery is performed under guidance from the nondominant hand, with the dominant hand used to manipulate the instruments. When compared with classical nasal and sinus surgeries, endonasal endoscopic surgery represents a highly functional and minimally invasive approach.

Endoscopic endonasal surgery has increased in popularity over the last 20 years to become one of the basic tools available to otorhinolaryngologists.

Innovations in navigation, computer-guided surgery, and three-dimensional (3D) imaging have allowed for transnasal and endonasal endoscopic approaches to lesions in the sinuses, nasopharynx, skull base, and intracranial regions.

Although these approaches are superior to both open and microscopic surgeries, due to being less invasive, achieving greater exposure of the target area and conferring advantages in terms of the instruments used, several limitations of endoscopic surgery have emerged. For example, one-handed surgery was found to prolong the duration of surgery by at least 15% [1]. In endoscopic endonasal surgery, fatigue or trembling of the hand as well as the capacity of instruments to move only in a single plane, their rigidity, and the fact that they must be removed after every attempt are the most commonly encountered problems. The two-dimensional (2D) view provided by endoscopes precludes a sensation of depth; therefore, deep and complex anatomical regions, such as the skull base and intracranial regions, are difficult to manage [2, 3]. In addition to dural defects, CSF fistula damage is the major complication that must be addressed in endonasal surgery. Furthermore, defects in the skull base should be repaired, which requires advanced technical skills and meticulous microsurgery [4, 5]. In particular, large, lateral skull base lesions are more likely to cause dural defects [3]. One-handed manipulation of instruments limits suturing capability, which is problematic in cases requiring graft sealing or a vascularized nasoseptal flap [6]. To repair defects on the posterior wall of the frontal sinus, endoscopic sinus surgery remains inefficient [7].

Overall, endoscopic surgery can be considered as a non-ergonomic approach [3]. An increasing number of reports have been published on bimanual and dynamic endoscope use [8]. To overcome the drawbacks associated with the 2D view provided by endoscopes, Felisati and Zaidi assessed the efficacy of a 3D endoscope that provided stereoscopic views,

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ultimately resulting in superior tissue manipulation and depth sensation, especially for cases with deep tumoral lesions [3, 9, 10]. In pediatric patients, the skull base exhibits an age-dependent—but sex-independent—structure, in addition to slow and stepwise development. Further development of the skull base can be disturbed by endoscopic endonasal skull base approaches through particular corridors. Banu et al. reported a novel set of anatomical parameters for assessing the developmental state of the skull base, and described the utility of those parameters with respect to preoperative planning for treating pediatric skull base lesions [11, 12].

To allow for two-handed surgery, simulations and models of different endoscope holders have been developed since 2005, serving as the prototypes of surgical robots [13, 14].

59.2 Development of Surgical Robots

Scientists have been able to overcome the aforementioned restrictions on surgical procedures. In1990, Computer Motion (Sunnyvale, CA, USA) developed a robot for the National Aeronautics and Space Administration (NASA) to fix faults in spacecraft that astronauts were unable to reach. This robot, called AESOP (Automated Endoscopic System for Optimal Positioning Robotic System), was the first to be approved by the Food and Drug Administration (FDA) to hold an endoscope inside the human body and is controlled by the human voice. In 1995, two arms were added to AESOP, which was renamed ZRSS (ZEUS Robotic Surgical System) and facilitated minimally invasive surgery by allowing for the insertion of instruments. In 1996, animal studies commenced, and instruments that were developed specifically for the robot were approved by the FDA in 2001. In 2003, Computer Motion merged with Intuitive Surgical (Sunnyvale, CA, USA) and renamed their surgical system the Da Vinci Surgical System.

In terms of the advantages of surgical robots with respect to overcoming the limitations of endoscopic endonasal surgery, the Da Vinci system provides a high-definition 3D view with ×16 magnification. Transorally, or through very small skin incisions, minimally invasive surgery can be performed. Tremor-filtering robotic instruments, while mimicking hand wrist motion, have the capacity for 540° movement in seven planes. During robotic surgery, the console surgeon can control the instruments with both hands, and the patient cart can be used for aspiration and to manipulate retractors to achieve exposure (Fig. 59.1a, b). Additionally, sutures can be applied with two hands and surgical instruments can be left in the surgical field. These advantages allow for safer, easier, and more ergonomic surgery.

In 2005, Hockstein et al. assessed the transoral usage of the Da Vinci system in cadavers and dummies [15]. In 2007, O'Malley and Weinstein first described Transoral Robotic Surgery (TORS) for supraglottic partial laryngectomy, radical tonsillectomy, and tongue base reduction [16]. TORS can be applied to the oropharynx, tongue base, pharyngeal wall, hypopharynx, pyriform sinus, parapharyngeal space, and larynx; an alternative for thyroid and head and neck diseases is the transaxillary approach. Treatment of laryngocele in pediatric cases with TORS is yet to be reported in the literature [17, 18]. New surgical applications of the Da Vinci system are being reported with increasing frequency.

Robotic series are being reported about a list of diseases which were formerly treated with classical open techniques. Techniques in TORS differ from abdominal robotic surgeries. TORS application is shown in Fig. 59.2a–c.

59.3 Approaches to the Nose, Sinuses, and Neighboring Structures

59.3.1 Findings from Cadaveric Studies

In 2007, O'Malley and Weinstein described the use of cervical TORS as a combined method in both cadavers and canines. Here, a port was introduced into the cavity through a small submandibular skin incision. Using this method, repair of nasopharyngeal, clivus, sphenoid, pituitary sella, and suprasellar regions was achieved [16]. Also in 2007, Hanna et al. described the use of a combined robotic method in a cadaver (bilateral sublabial incision plus wide anterior maxillary antrostomy) by application of the Caldwell-Luc procedure [2]. They reached the nasal cavity with endoscopic bilateral wide middle meatal antrostomies, in addition to posterior nasal septectomy. Then, they switched to robotic surgery, with a camera arm furthered through one nostril to visualize the nasal cavity. Instruments placed on surgical arms were inserted through anterior and middle antrostomies into the nasal cavity. Using this method, anterior and posterior ethmoidectomy, sphenoidectomy, and middle and superior turbinectomies can be performed with a robot and the surgical region can be enlarged if necessary, such that repairs in the anterior and central skull base, cribriform plate, fovea ethmoidalis, medial orbital wall, planum sphenoidale, sella turcica, suprasellar and parasellar regions, and nasopharynx can be achieved and pterygopalatine fossa and clivus dissections can be performed. In such surgeries, a 3D view, sensation of depth and two-handed, tremor-free use of instruments are the main advantages [2].

In 2008, Ozer et al. described a transoral robotic nasopharyngectomy in a cadaver. Without performing an external incision, soft palate division was used to expose the nasopharynx, with the arms placed transorally [19].

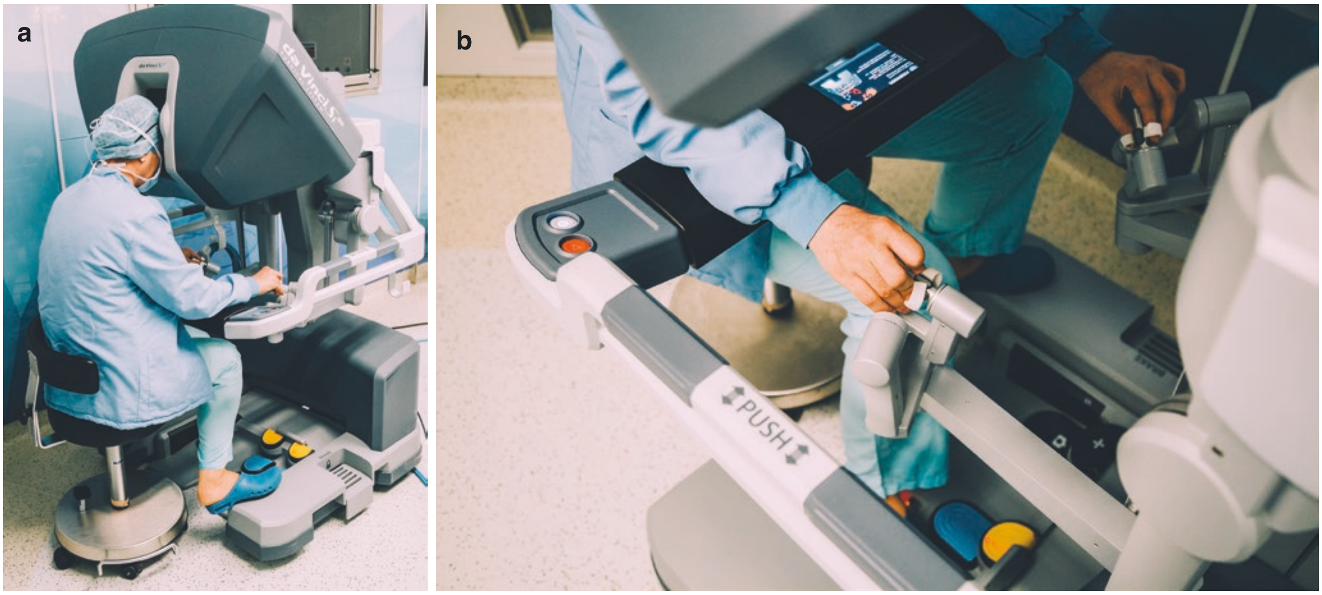

Fig. 59.1 (**a**) Da Vinci® Surgical Platform has two parts: Surgeon Console and Patient Cart. (**b**) Console surgeon remote arms and instrument with master manipulator and foot plate

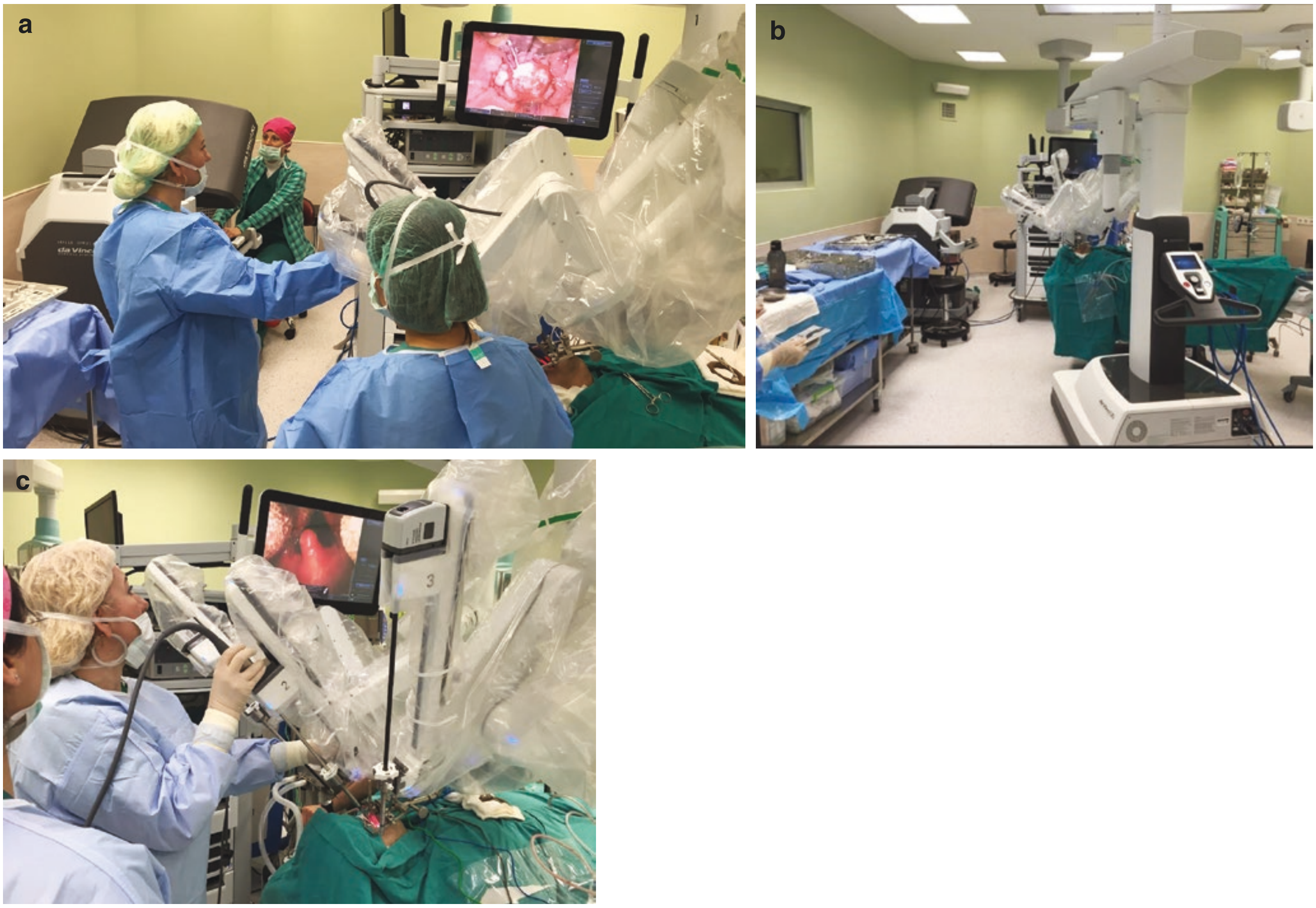

Fig. 59.2 Transoral approach robotic surgery is seen in this figure. (**a**) The figure shows the operating room layout for the Da Vinci Surgical system. (**b**) The setup of Da Vinci Surgical platform for transoral robotic surgery and docking. (**c**) Patient Surgeon is sterile in patient Cart, is responsible for placement of instruments, aspiration of blood and smoke, and controls surgical field. Pharyngolaryngeal retractor was used for exposition

In 2011, Kupferman and Hann are paired dural defects using transmaxillary and transantral approaches in a cadaver model [20].

Ina 2012 cadaver study, Dallan et al. reported that a combined transoral-transnasal robotic nasopharyngectomy was more effective than a pure transoral approach [21]. In 2013, Carrau used endonasal endoscopy to repair the infratemporal fossa, nasopharynx, clivus (posterior skull base), and craniovertebral junction, with TORS used for dissection of the pharyngeal space, infratemporal fossa, nasopharynx, and Eustachian tube. These authors reported that TORS combined with endonasal endoscopic approach (EEA) could be used in these regions [22].

Ozer et al. used transoral, transcervical, transnasal, and transpalatal corridors to reach the skull base and suggested the introduction of a suprahyoid transcervical port for infratemporal fossa approaches. However, they considered submandibular transcervical TORS to be difficult [19].

In 2014, Chouvet drilled the hard palate of a cadaver for approaches to the sella turcica and skull base. Mucosa closure was achieved with robotic arms [23].

In 2015, Cho performed cadaveric nasopharyngectomies using bilateral transantral or endonasal-transantral ports without transpalatal or skin incisions. Initially, endoscope-assisted mega antrostomy and posterior septectomy were performed. Upon gingivobuccal incision, a maxillary window was opened. Bilateral transantral instruments were inserted under the guidance of a camera arm placed through the nose such that nasopharyngeal surgery could be done [24].

The nose and paranasal sinuses have been transformed from locations in which primary diseases can be treated safely to natural surgical corridors allowing surgeons to reach deeper places.

59.3.2 Inpatient Studies

Wei and Ho (2010) reported that recurrent nasopharyngeal carcinoma after radiotherapy could be successfully resected by soft palate splitting with TORS [25]. Wei also compared surgical salvage treatment and chemoradiotherapy for recurrent nasopharynx carcinoma in 2011 and stated that in cases of recurrent nasopharynx carcinoma, robotic surgery should be considered as the optimal treatment modality.

Tsang et al. reported a combined transnasal endoscopic and transoral robotic approach with soft palate splitting for treatment of a recurrent nasopharynx carcinoma by exposing the nasopharynx and excising the tumor. They also resected the anterior wall of the sphenoid base superiorly [26]. In 2013, they modified their approach to the palate by using a TORS-assisted lateral palatal flap [27], and in 2015, they reported the results of robot-assisted nasopharyngectomies in 12 patients with recurrent nasopharynx carcinoma. Using this method, the preliminary results showed that the 2-year local control ratio was 86%, the 2-year survival rate was 83%, and the disease-free survival rate was 61%. In 2014, 312 recurrent nasopharynx carcinoma patients were evaluated retrospectively by Chan, who suggested an endoscopic or robotic approach for small tumors on the posterior wall [28, 29].

Tao, however, proposed that endoscopic surgery should be restricted to exposing tumors and providing a negative surgical margin; therefore, it should be performed by highly experienced surgeons only. They also suggested transoral robotic surgery (TORS) for recurrent T1 and T2 tumors or tumors at an appropriate distance from the internal carotid artery and skull base [30].

In 2010, O'Malley reported removal of parapharyngeal space tumors in ten patients with TORS [31]. Mendelshon (2015) used TORS for safe and precise removal of parapharyngeal lipomatous masses; TORS is safe and effective in the parapharyngeal region [32]. Different classical approaches are applied to parapharyngeal space in accordance with the location, nature, and extent of the disease. External approaches, which include a range differing from parotid lobectomy to mandibulotomy, are single or combined approaches with higher morbidity. Because of the complexity of anatomy of the region that contains vital neurovascular structures, any intervention to the region bares potential of high risk of complication. In selected cases transoral approach provides prevention of complications and lowers the morbidity. TORS specifically lowers first bite syndrome. A parapharyngeal pleomorphic adenoma that was managed with TORS was presented in Figs. 59.3a–e and 59.4a, b.

59.4 Disadvantages of Surgical Robots

There are several limitations associated with robotic surgery. First, robotic surgery is an intuitive method due to the absence of tissue feedback. Second, the technique is still somewhat unwieldy: the endoscopes and instruments are not sufficiently fine and there is a lack of variety among them. Therefore, it is necessary to develop drills and rongeurs that can be placed transorally or transnasally such that more precise surgery can be performed [2]. Finally, robotic systems and their associated service costs are very high.

59.5 Future Issues

In the near future, the Da Vinci system is expected to undergo further technological development [33]. At present, the system remains unwieldy and relatively invasive with respect to the paths and corridors currently being used

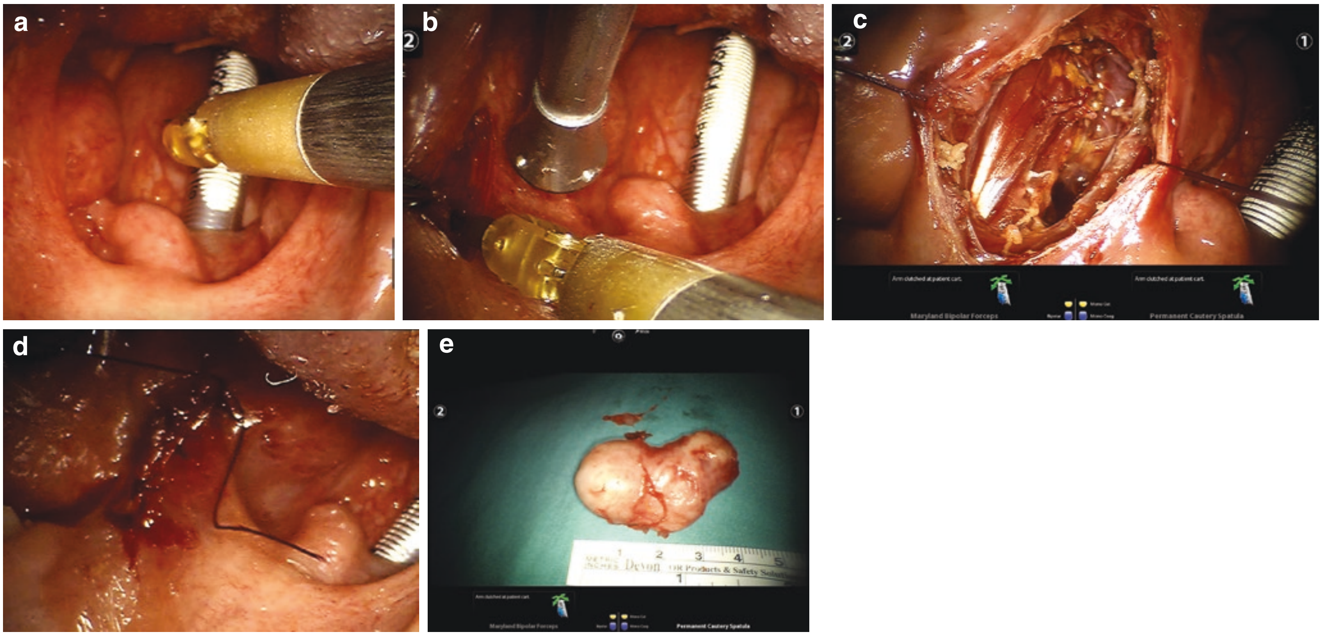

Fig. 59.3 Seventeen-year-old boy admitted with orbitocranial headache. Magnetic resonance imaging (MRI) revealed left parapharyngeal mass. The parapharyngeal mass was excised with transoral robotic approach without complication. (**a**) Robotic intraoral view of the mass that pushes tonsil toward midline. (**b**) A small incision is performed. (**c**) The mass is dissected from the surrounding tissue. (**d**) The incision was sutured 2/0 vicryl. (**e**) The excised mass is 40 × 18 × 12 mm in diameter and diagnosed as pleomorphic adenoma

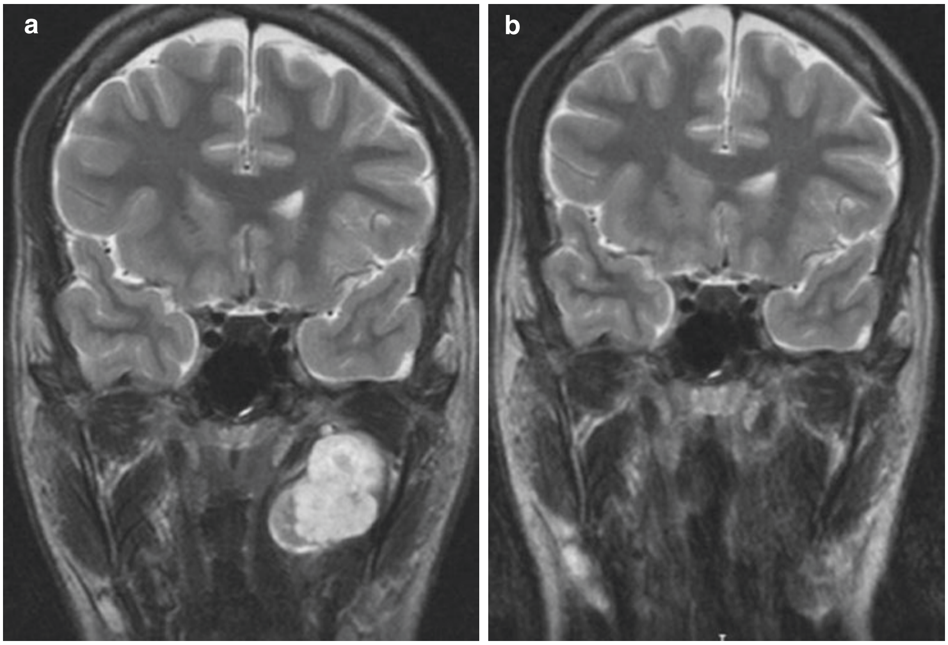

Fig. 59.4 Preoperative T2-weighted MRI (**a**) demonstrating the solid mass with high intensity on T2- and T2-weighted MRI on 6 months postoperatively (**b**) is shown. *The scenes are from personal archive of F.T. Kayhan. All rights are reserved

to the reach nose, sinuses, and skull base. Several robotic prototypes are being developed, with a tiny size allowing for delicate drilling, but these remain in the laboratory research phase [34].

In July 2015, the Flex Robotic System (Medrobotics Corp., Raynham, MA, USA) was approved by the FDA. The system has two 3-mm-sized instruments and a flexible endoscope that can be inserted via a single port. Particularly for oropharynx cancer, the Flex system has been successful in cadaver models, in terms of safety and feasibility [35].

The Flex system is also useful for repairing the larynx and hypopharynx. Preliminary results also showed that the Flex system was easier to set up than the Da Vinci system, the major disadvantages of which are its relative bulkiness, rigidity, and absence of tactile feedback. The Flex system permits work to be carried out in a more confined area, owing to its smaller (3 mm) endoscopes; it also allows entry from a single port (thereby avoiding collisions between instruments and the endoscope), is characterized by greater flexibility with respect to both the instruments and the endoscope, and can reach beyond the tongue base [36].

The Flex Robotic System is expected to be applied in sinonasal and nasopharyngeal regions, among others, once surgeons gain sufficient experience of using the technology. Currently, technological research is focused on producing more ergonomic, cheaper, safer, and smaller sized robots with delicate and fine instrumentation; commensurate with such advances, robotics usage will increase. Continual research and striving will yield safer and more effective surgical systems, which will in turn give rise to novel surgical approaches.

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