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Original Investigation

A Haptic Guided Robotic System for Endoscope Positioning and Holding

Haptik Kontrollü Endoskop Tutucu ve Pozisyonlandırıcı Robotik Sistem

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ABSTRACT

AIM: To determine the feasibility, advantages, and disadvantages of using a robot for holding and maneuvering the endoscope in transnasal transsphenoidal surgery.

MATERIAL and METHODS: The system used in this study was a Stewart Platform based robotic system that was developed by Kocaeli University Department of Mechatronics Engineering for positioning and holding of endoscope. After the first use on an artificial head model, the system was used on six fresh postmortem bodies that were provided by the Morgue Specialization Department of the Forensic Medicine Institute (Istanbul, Turkey).

RESULTS: The setup required for robotic system was easy, the time for registration procedure and setup of the robot takes 15 minutes. The resistance was felt on haptic arm in case of contact or friction with adjacent tissues. The adaptation process was shorter with the mouse to manipulate the endoscope. The endoscopic transsphenoidal approach was achieved with the robotic system. The endoscope was guided to the sphenoid ostium with the help of the robotic arm.

CONCLUSION: This robotic system can be used in endoscopic transsphenoidal surgery as an endoscope positioner and holder. The robot is able to change the position easily with the help of an assistant and prevents tremor, and provides a better field of vision for work.

KEYWORDS: Robot, Endoscope, Transsphenoidal surgery

ÖZ

AMAÇ: Transnazal transsfenoidal cerrahide endoskopu tutmak ve hareket ettirmek için kullanılan robotik sistemin uygulanabilirliğini, avantajlarını ve dezavantajlarını ortaya koymayı amaçladık.

YÖNTEM ve GEREÇLER: Çalışmada Kocaeli Üniversitesi Mekatronik Mühendisliği Bölümü tarafından geliştirilen "Stewart Platform" tabanlı endoskop tutucu ve konumlandırıcı robotik sistem kullanılmıştır. Yapay kafa modeli üzerinde ilk kullanımdan sonra, Adli Tıp Kurumu Morg İhtisas Dairesinde (İstanbul, Türkiye) altı taze kadavrada uygulama yapılmıştır.

BULGULAR: Robot sistemi için gerekli kurulum kolay oldu ve kayıt prosedürü ile robotun kurulumu yaklaşık 15 dakika sürdü. Komşu dokular ile temas veya sürtünme halinde temas algılayan kol aracılığıyla direnç hissedildi. Fare ile endoskop maniplasyonu için gereken adaptasyon süreci daha kısa oldu. Robotik sistem ile endoskopik transsfenoidal yaklaşım mümkün oldu ve endoskop robotik kol yardımıyla sfenoid ostiuma dek ilerletildi.

SONUÇ: Bu robotik sistem endoskopik transsphenoidal cerrahide endoskop tutucu ve konumlayıcı olarak kullanılabilir. Robot asistan yardımı ile titreşim olmadan kolayca konumunu değiştirmekte, böylece daha iyi bir vizyon ve çalışma alanı sağlamaktadır.

ANAHTAR SÖZCÜKLER: Robot, Endoskop, Transsfenoidal cerrahi

INTRODUCTION

Different surgical techniques and instruments have been used by neurosurgeons for sellar and parasellar lesions. Important milestones in the development of neurosurgical techniques in recent years include microsurgery, neuro-endoscopy, neuronavigation and advanced intraoperative imaging techniques (35). The use of an endoscope in neurosurgery has provided a new approach to midline tumors of the anterior skull base. The increased use of endoscopic skull base approaches may be attributed to a larger trend toward more "minimally invasive" techniques (23). The handicap of endoscopic surgery for the surgeon is the restriction to one hand for manipulation whereas the other hand is holding the endoscope (34). Because of the inherent difficulty of holding the endoscope and thus having only one hand available for the surgical procedure, a second surgeon holds the endoscope in a limited working area or a stationary endoscope holder is used.

Innovations in the field of mechatronics are being adjunct to the developments in medicine. The use of robots in medicine is a developing area. Robots may have some advantages when compared with the surgeons (for example, higher accuracy, better sensors) and assist them in their work or perform parts of the work independently. The "Robot Institute of America" defines a robot as "A reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks." (10).

The robotic system in the operation room can be divided into a supervisory-controlled system, telesurgical system, and shared-control system. In a supervisory-controlled system, the robot automatically performs the operation, based on a specific set of instructions that supervised by the surgeon. Shared-control robotic systems assist surgeons during surgery, the surgeon has full control of the procedure and the robot offers steady hand manipulation of the instrument (4, 27). Telesurgery, also called remote surgery, is a system in which the surgeon controls the robot in real time via the haptic interface, at a site removed from the patient. A number of robotic devices and technical applications for various medical fields have been developed, da Vinci (Intuitive Surgical, Inc., Sunnyvale, CA), Zeus (Computer Motion, Inc., Goleta, CA), and Robodoc (Integrated Surgical Syst Davis, CA), and a variety of medical robots have been developed for stereotactic neurosurgery such as Neuromate (Integrated Surgical Systems, Davis, CA) and Evolution 1 (Universal Robot Systems, Schwerin, Germany), NeuRobot (Shinshu University School of Medicine, Japan) (15, 36).

In this study, we examined the ability of our industrial robotic arm to perform basic neurosurgical procedures and evaluated the feasibility of using a robot for holding and maneuvering the endoscope. The article focused on the advantages of the robot in a shared-control system as a scope holder.

MATERIAL and METHODS

The validity of the SP (Stewart Platform) was proven in the endoscopic transsphenoidal surgery performed on an artificial skull model at the Kocaeli University Mechatronics Laboratory and on cadavers in the Morgue Specialization Department of the Forensic Medicine Institute, Istanbul.

The approach to the nostril was performed on the artificial model with the spatial mouse and the haptic arm. After attachment of the endoscope holder to the Stewart platform at Kocaeli University, the concha, choana and sphenoid ostium were visualized on cadavers.

Stewart Platform System

The system used in this study was a Stewart Platform-based robotic system that was developed for endoscope positioning and holding by Kocaeli University, Department of Mechatronics Engineering.

The system consists of a parallel manipulator and other parts such as controller, 3D mouse, six DOF haptic, six DOF force-torque sensor, power supply, emergency stop circuit and controller-robot connector board and endoscope holder.

SP has a special structure that includes two main bodies (mobile and fixed plates), six linear motors, and joints. The DSpace DS1103 real-time controller is used for the implementation of control algorithms.

Robot kinematics defines geometric relationships between the joint and Cartesian space of a robot. Coordinate systems can be placed at the center of the base plate and upper mobile plate as shown in Figure 1 in order to find the inversenematics of the SP.

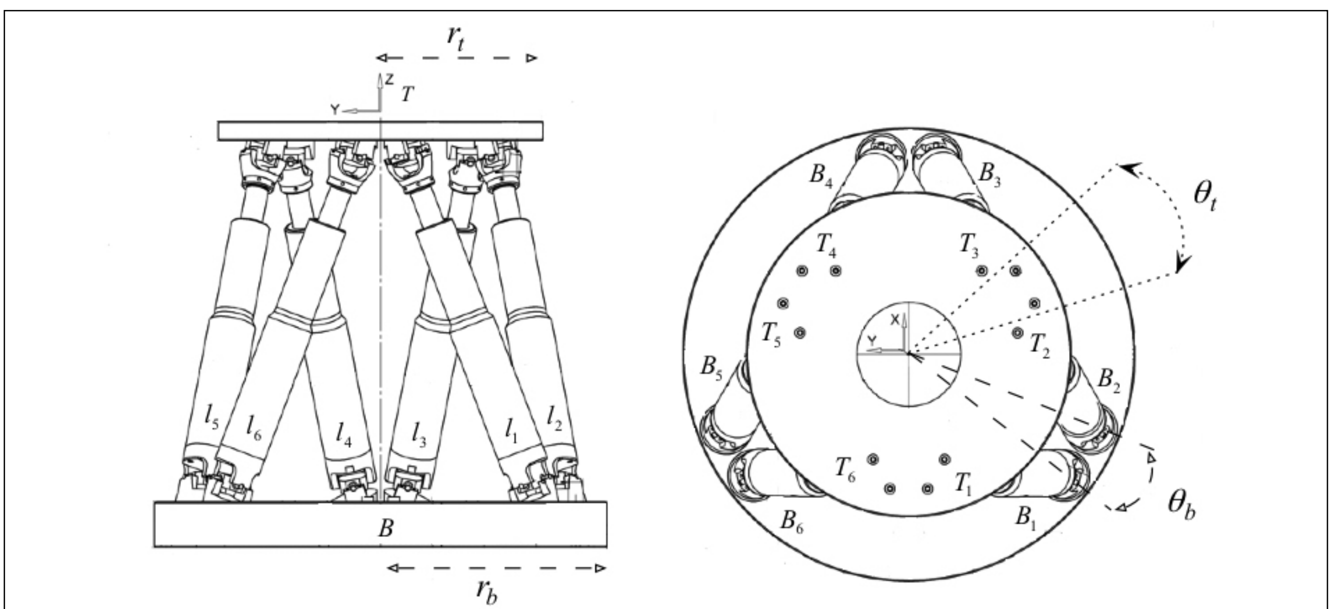

Figure 1: Kinematic configuration of the SP.

SP can be guided using the 6 DOF haptic device and mouse. The workspace of the haptic device and SP were matched to each other in this work, but the haptic may also be used to work incrementally. The mouse also works in an incremental manner.

Haptic systems are used in many applications such as robot control and virtual reality. The Phantom Omni can be programmed using the OpenHaptics library with C++. A VisualStudio 2008 project has been developed in the C++ environment in order to be integrated into the system and control the Stewart Platform by the haptic. The Phantom Omni haptic system was developed by Sensable. It is capable of three degrees of freedom force feedback generating six degrees of freedom position information (Figure 2).

The robot can be controlled via a joystick instead of the 6 DOF haptic. An m-file (Matlab software) was developed for reading the joystick via USB. Motion commands were transferred to the DSpace control card via the RS-232 serial port.

Artificial Model

The Stewart Platform-based system was used first on an artificial head model in Kocaeli University Mechatronics Laboratory (Figure 3A, B). The size of the artificial model was identical as a normal adult human head, and the model has two nostrils for bimanual surgery. At this level, the endoscope holder was fixed to the Stewart Platform in an optimal position and access to the nostril was ensured.

Figure 2: Phantom Omni Haptic.

Cadaveric Dissection

The study was performed on six fresh postmortem bodies that were provided by the Morgue Specialization Department of the Forensic Medicine Institute (Istanbul,Turkey). The cadaveric sample was placed in the supine position. The Stewart Platform was positioned at the left side of the cadaver at the level of chest. In addition, a surgeon was at the right side of the patient and could observe the operation field using a bedside monitor (Figure 4A-C).

RESULTS

The setup required for robotic system was easy. The time for the registration procedure and setup of the robot takes 15 minutes.The normal setup of the operating room for this procedure was the same, and only a table was placed at the level of chest. At the beginning of the procedure, the endoscope was placed 5 cm above the nostril. The time for the endoscopic part of the procedure ranged from 7 to 19 minutes. The transsphenoidal sellar approach was possible with the endoscope holder attached to the Steward platform. The positioning and placement of the robotic system allow enough workplace in the operating room for the surgeon and the second surgeon, and provide access to the nose for operating with the other instruments simultaneously. The endoscope was slowly moved forward with visual control through the endoscopic images, using a special joystick device. Endoscopic maneuvers with the mouse or haptic arm showed us the inferior turbinate and the middle turbinate. The middle turbinate was pushed laterally with a dissector. We had to increase the number of maneuvers with the mouse or haptic arm in order to prevent the contamination of the

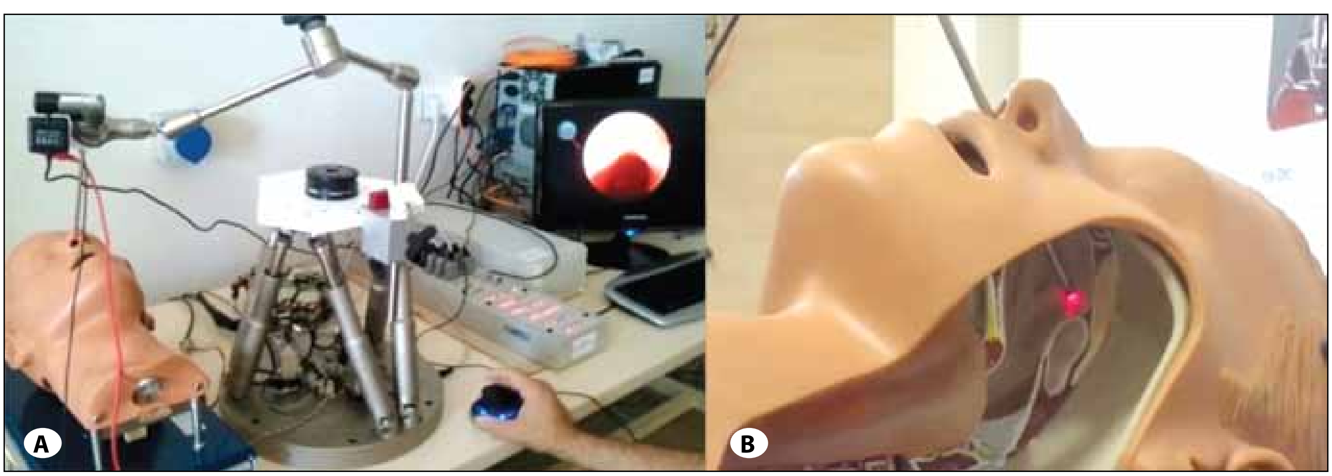

Figure 3: A) The picture shows the attachment of the endoscope to the Stewart Platform. **B)** Insertion of the endoscope into the right nostril of the artificial model.

endoscope during the passage through the medial side of middle turbinate (experience was needed at this stage). resistance was felt on the haptic arm in case of contact or friction with adjacent tissues. The adaptation process was shorter with the mouse to manipulate the endoscope. The endoscope was guided to the sphenoid ostium with the help of the robotic arm and the superior turbinate was visualised (Figure 4C). There was no discordance between the primary surgeon and the robotic arm. Working with three instruments in the surgical field was comfortable and bimanual surgery was feasible. We did not have to wait or stop the process to change endoscope position. Thereby, the elimination of the need for manual stabilization of the endoscope allows the use of both hands at the same time for surgical manipulation and reduces the vibration.

The primary surgeon was more comfortable with the working conditions. In contrast, the assistant at the joystick device has a more difficult job because the assistant has to look at the operating field and position his/her instruments around the robotic arm. In addition, the assistant has to follow both the operating area and the screen to assist effectively.

DISCUSSION

Minimally invasive access to complex surgical lesions has provided patients with better outcomes and fewer complications (2, 31). Device development and newer instrumentation have provided us tools that improve care to patients (32). The development of the operating microscope, neuroendoscopy, neuronavigation and microinstruments has offered significant improvement in modern neurosurgery (36).

The use of an endoscope during microsurgical transsphenoidal surgery was first reported by Guiot and co-workers in 1963 (16). Jankowski and colleagues were the first in the literature to report the pure endoscopic approach to the pituitary in 1992 (19). Recently, the pure endoscopic approach has gone into use for pituitary surgery (6, 7, 9, 12, 20, 28).

The endoscopic transsphenoidal approach to the sella is becoming more popular and is preferred by an increasing number of centers for the treatment of pituitary tumors. The current trend in the surgical treatment of suprasellar, petroclival, infratemporal and other skull base tumors is the use of extended and expanded transnasal endoscopic approaches (23). However, there are ergonomic limitations for the presently available endoscopic skull base techniques.

The learning curve is a major disadvantage in endoscopic transnasal surgery for the neurosurgeon who is already skilled in microscopic surgery, because of the need for holding the endoscope with the non-dominant hand, and manipulating the surgical instruments with the other hand (22).

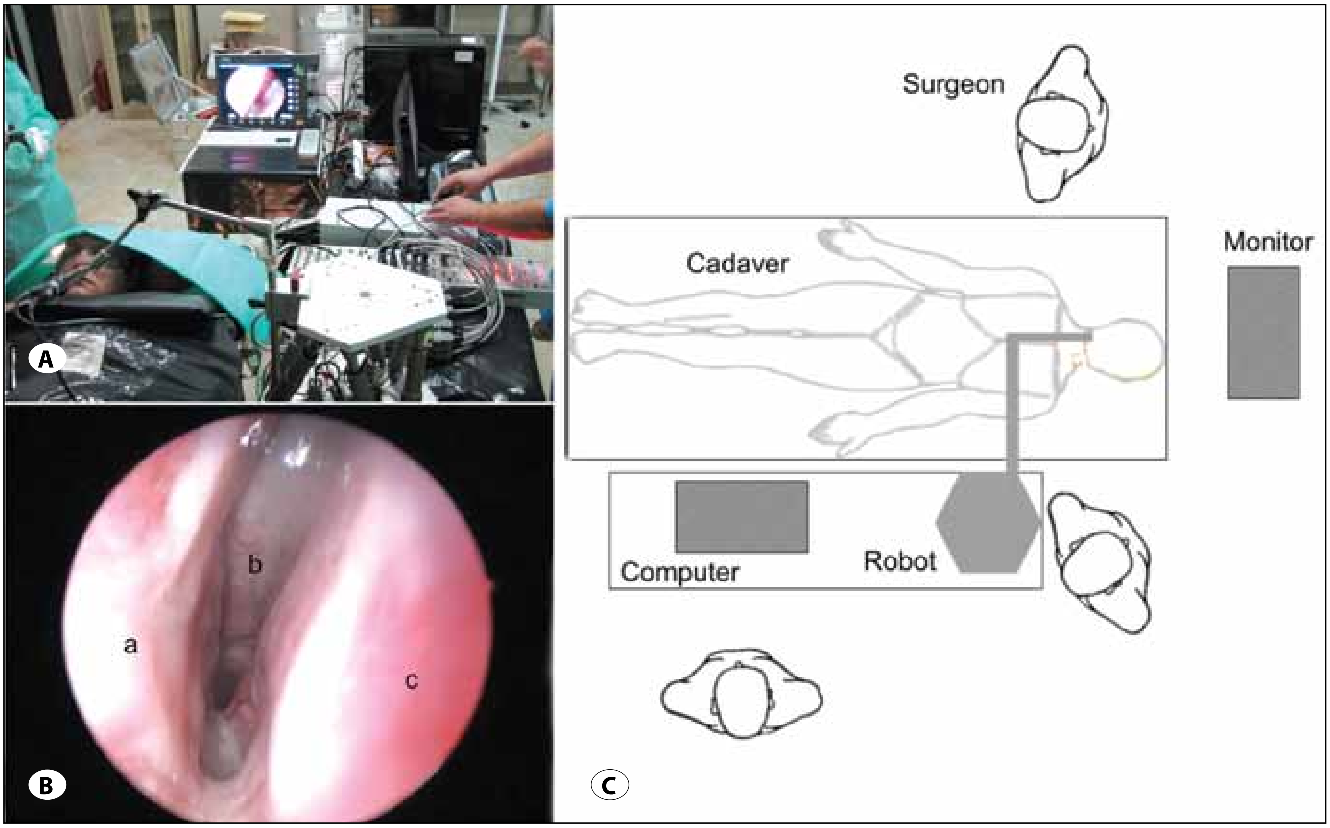

Figure 4: A, C) The pictures show the orientation and position of the robotic endoscope holder system in the operating room. **B)** Anterior wall of sphenoid sinus was visualized during cadaveric dissection (a. nasal septum, b. anterior wall of the sphenoid sinus, c. middle concha).

Bimanual endoscopic surgery is possible only when the endoscope is guided by an assistant or positioned with a mechanical holder (23). Castelnuovo described the “four-handed” technique, wherein the operation is performed through a nostril using the endoscope and an additional instrument parallel to the endoscope, while another instrument is inserted through the other nostril by a second surgeon (8). If a third hand was available for handling of the endoscope, it occupies space and requires coordination of two different surgeons movements (21, 33).

The endoscope-holder allows the surgeon to use both hands while providing a continuous view on the monitor screen. As described in this manuscript, our robotic system is working as a scope holder and enables the neurosurgeon to perform bimanual surgery.

Endoscopic neurosurgery is probably going to improve in the following years by further innovations in optical physics, electronics, and robotics. Specific implementations in endoscopic systems that provide remarkable progress in minimally invasive surgery include robotic surgical technology (37).

Robots are characterized by a constant working performance. Their behavior is independent of mental influences, they perform movements with very high spatial and temporal precision and can be operated remotely.

A variety of robots have been developed for surgery in recent years (5, 13, 25, 32), and their benefits have begun to be quantified. The first use of an active motion robot for soft-tissue surgery was performed in 1991 (11). In 1994, the United States Food and Drug Administration approved the first robot for clinical use. This Automated Endoscopic System for Optimal Positioning (AESOP) was developed to hold a laparoscopic camera (14, 26). Recently, the United States Food and Drug Administration approved the Zeus and the daVinci robotic systems for limited clinical application in chest and abdominal surgery. Da Vinci (3) (Intuitive Surgical, US) is a well-known commercial robotic system. In this case, the surgical robot is controlled based on a master-slave system; thus, the robot performs the surgery based on the coordinates given by the surgeon’s motion input through the master console.

Robotic technology was first introduced into neurosurgery in image-guided devices. Adler et al. (1) used a robotic system to manipulate a lightweight X-band linear accelerator for closed-cranium radiation of a lesion localized with CT or MR imaging in 1990 (27). This system (CyberKnife) has been effectively incorporated into neurosurgical practice. Goto et al. (15, 18) presented a master-slave micro-manipulator system for neurosurgery. This NeuRobot system consists of a 3D endoscope and three robotic arms, and was used to perform an endoscopic third ventriculostomy. “Penn” and the MD Anderson group first used a transoral approach to the skull base with a robotic system in a cadaveric specimen (17, 29). Transoral surgical procedures have been performed with currently available commercial systems, but there is no existing commercial system used by the transnasal approach.

We used the transnasal approach to the sella in this study. The advantage of our robot used as a holding and positioning device for the endoscope is the possibility of performing very smooth slow motions in critical regions. The neurosurgeon controls the robot via a special joystick, which scales down the movements of the surgeon’s hand to sensitive movements of the endoscope. The robot-guided endoscope can be held in any position and can be immediately stopped, without unwanted movements. For complete freedom of movement, 6 DOFs are required. DOF (degree of freedom) refers to the number of possible movements that can be made at a joint. These movements can either be translational or rotational. With 6 DOF’s, our robot could easily perform all the necessary movements. The design of the robotic system allows flexible pre-positioning of the robot according to the patient’s anatomic features. Another advantage of our system in contrast to the robotic systems working with navigation is that there is no need for stabilization of the head. The disadvantages of the master-slave robots such as high cost, excessive size and difficulty of transfer do not exist in our system.

We specifically developed a new system for endoscopic transnasal approaches. The small size of the system is appropriate for endonasal surgery. The traditional safety methods designed for industrial robots are not currently available for medical robots and therefore some safety mechanisms are still missing in our robotic system.

Robotic systems can take over a concentration-consuming and tedious task, such as holding and tracking of an endoscope, which often has to be carried out in a stressful posture. In addition, an unintended rotation of the endoscope, which would lead to a tilting of the perceived horizon and an orientation that can result in difficulties and incorrect positioning, is avoided (30).

Interestingly, the learning times for robotic procedures appear to be shorter than their endoscopic counterparts (24).

We showed that robot-assisted, transnasal sellar surgery was technically possible in this study but completely robotic surgery requires the development of new surgical instruments and increased experience.

CONCLUSION

Robots offer a number of advantages for surgery; Improving the quality of surgery, performing operations that are manually impossible, reduction in the operating time and assistance functions.

In our experience with endoscopic skull base surgery, a robotic system will permit the surgeon an easier working environment and better treatment of patients if the space-saving, user-friendly, tremor-free robotic systems are adapted to existing surgical procedures.

REFERENCES

1. Adler JR Jr, Murphy MJ, Chang SD, Hancock SL: Image-guided robotic radiosurgery. Neurosurgery 44:1299–1307, 1999
2. An Anatomical Approach to Minimally Invasive Spine Surgery. Perez-Cruet MJ, Khoo LT, Fessler RG, (eds). St. Louis, MO: Quality Medical Publishing, 2006
3. Arata J, Kenmotsu H, Takagi M, Hori T, Miyagi T, Fujimoto H, Kajita Y, Hayashi Y, Chinzei K, Hashizume M: Surgical bedside master console for neurosurgical robotic system. Int J Comput Assist Radiol Surg: 8(1):75-86, 2013
4. Awang MS, Abdullah MZ: Robotic neurosurgery: A preliminary study using an active vision-guided robotic arm for bone drilling and endoscopic manoeuvres. Malays J Med Sci 18(2):53-57,2011
5. Birke A, Reichel H, Hein W, Schietsch U, Hube R, Bernstein A, Kruger T: ROBODOC: A path into the future of hip endoprosthetics or an investment error? Z Orthop Ihre Grenzgeb 138:395–401, 2000
6. Cappabianca P, Cavallo LM, Colao A, de Divitiis E: Surgical complications associated with the endoscopic endonasal transsphenoidal approach for pituitary adenomas. J Neurosurg 97:293–2982, 2002
7. Cappabianca P, Cavallo LM, de Divitiis E: Endoscopic endonasal transsphenoidal surgery. Neurosurgery 55:933–941, 2004
8. Castelnuovo P, Pistochini A, Locatelli D: Different surgical approaches to the sellar region: Focusing on the "two nostrils four hands technique." Rhinology 44: 2–7, 2006
9. Cho DR, Liau WR: Comparison of endonasal endoscopic surgery and sublabial microsurgery for prolactinomas. Surg Neurol 58:371–376, 2002
10. Cleary K, Nguyen C: State of the art in surgical robotics: Clinical applications and technology challenges: Comput Aided Surg 6(6):312-328,2001
11. Davies B: A review of robotics in surgery: Proc Inst Mech Eng 214:129–140, 2000
12. Divitiis E, Cappabianca P, Cavallo LM Endoscopic transsphenoidal approach: Adaptability of the procedure to different sellar lesions. Neurosurgery: 51:699–707, 2002
13. Drake JM, Joy M, Goldenberg A, Kreindler D: Computer- and robot-assisted resection of thalamic astrocytomas in children. Neurosurgery 29:27–33,1991
14. Geis WP, Kim HC, Brennan EJ Jr, McAfee PC, Wang Y: Robotic arm enhancement to accommodate improved efficiency and decreased resource utilization in complex minimally invasive surgery procedures. Stud Health Technol Inform 29:471–481, 1996
15. Goto T, Hongo K, Kakizawa Y, Muraoka H, Miyairi Y, Tanaka Y, Kobayashi S: Clinical application of robotic telemanipulation system in neurosurgery. Case report. J Neurosurg 99(6):1082-1084, 2003
16. Guiot G, Rougerie J, Fourestler A, Fournier A, Comoy C, Vulmiere J, Groux R: Une nouvelle technique endoscopique. Exploration endoscopiques intracraniennes. La Presse Medicale 71:1225–1228, 1963
17. Hanna EY, Holsinger C, DeMonte F, et al: Robotic endoscopic surgery of the skull base: A novel surgical approach. Arch Otolaryngol Head Neck Surg 133:1209-1214,2007
18. Hongo K, Kobayashi S, Kakizawa Y, Koyama J, Goto T, Okudera H, Kan K, Fujie MG, Iseki H, Takakura K: Neu Robot: Telecontrolled micromanipulator system for minimally invasive microneurosurgery-preliminary results. Neurosurgery 51(4):985-988; discussion 988, 2002
19. Jankowski R, Auque J, Simon C, Marchal JC, Hepner H, Wayoff M: Endoscopic pituitary tumor surgery. Laryngoscope 102:198–202,1992
20. Jho HD, Alfieri A: Endoscopic endonasal pituitary surgery: Evolution of surgical technique and equipment in 150 operations. Minim Invasive Neurosurg 44(1):1–12, 2001
21. Kennedy DW: Functional endoscopic sinus surgery. Technique. Arch Otolaryngol 111:643–649,1985
22. Koc K, Anik I, Ozdamar D, Cabuk B, Keskin G, Ceylan S: The learning curve in endoscopic pituitary surgery and our experience. Neurosurg Rev 29:298–305, 2006
23. Kupferman ME, Hanna E: Robotic surgery of the skull base. Otolaryngol Clin North Am 47(3):415-423, 2014
24. Maan ZN, Gibbins N, Al-Jabri T, D'Souza AR: The use of robotics in otolaryngology-head and neck surgery: A systematic review. Am J Otolaryngol 33(1):137-146, 2012
25. Miller K, Chinzei K: New UWA robot: Possible application to robotic surgery. Biomed Sci Instrum 36:135–140, 2000
26. Nathan CO, Chakradeo V, Malhotra K, D'Agostino H, Patwardhan R: The voice-controlled robotic assist scope holder AESOP for the endoscopic approach to the sella. Skull Base 16(3):123-131, 2006
27. Nathoo N, Cavusoglu MC, Vogelbaum MA, Barnett GH: In touch with robotics: Neurosurgery for the future. Neurosurgery 56(3):421-433; discussion 421-433, 2005
28. Ogawa T, Matsumoto K, Nakashima T, Okano M, Ono Y, Fukushima K, et al: Hypophysis surgery with or without endoscopy. Auris Nasus Larynx 28:143–149, 2001
29. O'Malley BW Jr, Weinstein GS: Robotic skull base surgery. Arch Otolaryngol Head Neck Surg 133:1215-1219, 2007
30. Olinger A, Hildebrandt U: Endoskopische Operationen an der Wirbelsäule. In: Olinger A, Hildebrandt U (eds), Endoskopische Wirbelsäulenchirurgie: Thorakal, transperitoneal, retroperitoneal. Berlin: Springer, 2000:15-108
31. Minimally Invasive Spine Fusion: Techniques and Operative Nuances. Perez-Cruet MJ, Beisse R, Pimenta L, Kim DH (eds). St. Louis, MO: Quality Medical Publishing, 2011
32. Perez-Cruet MJ, Welsh RJ, Hussain NS, Begun EM, Lin J, Park P: Use of the da Vinci minimally invasive robotic system for resection of a complicated paraspinal schwannoma with thoracic extension: Case report. Neurosurgery 71(1 Suppl Operative):209-214, 2012
33. Poulose BK, Kutka MF, Mendoza-Sagaon M, Barnes AC, Yang C, Taylor RH, Talamini MA: Human vs robotic organ retraction during laparoscopic Nissen fundoplication. Surg Endosc 13:461–465, 1999

34. Sethi DS, Pillay PK: Endoscopic surgery for pituitary tumors. In: Friedman M (ed), Operative Techniques in Otolaryngology-Head and Neck Surgery, 1996:264–268

35. Wagner I, Tingelhoff K, Westphal R, Kunkel ME, Wahl F, Bootz F, Eichhorn K: Ex vivo evaluation of force data and tissue elasticity for robot-assisted FESS. Eur Arch Otorhinolaryngol 265(11):1335-1339, 2008

36. Zimmermann M, Krishnan R, Raabe A, Seifert V: Robot-assisted navigated endoscopic ventriculostomy: Implementation of a new technology and first clinical results. Acta Neurochir (Wien) 146(7):697-704, 2004

37. Zimmermann M, Krishnan R, Raabe A, Seifert V: Robot-assisted navigated neuroendoscopy. Neurosurgery 51(6):1446-1451; discussion 1451-1452,2002

38. Zada G, Liu C, Apuzzo ML: "Through the looking glass": Optical physics, issues, and the evolution of neuroendoscopy. World Neurosurg 79(2 Suppl):S3-13, 2013