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Review Article

Robots in Head and Neck Surgery

Avi Bansal [1], Vishal Bansal [2], Gourav Popli [3], Neha Keshri [4], Gagan Khare [5], Siddhartha Goel [6]

[1,3]Senior Lecturer, [2]Professor and Head, [6]Post Graduate Student Department of Oral and Maxillofacial Surgery, Subharti Dental College, Meerut
[4]Consultant Oral and Maxillofacial Pathologist, Meerut
[5]Reader,Department of oral And Maxillofacial Surgery, Seema Dental College, Rishikesh

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ABSTRACT

Robots in medicine and especially in surgery are of major interest today. Many of the challenges in the field of surgery can be made possible by using surgical robots and telemanipulators. The current view of this technology has certainly captured the surgeon's expedition to avail the least invasive procedures. Moreover, as the Head and Neck surgical procedures are complex and have potentially significant immediate postoperative morbidity and risk of mortality. So, the need to reduce trauma of such procedures is marking the introduction of robot assisted surgery. The goal of this review is to show how robotic surgery is advancing the care of head and neck surgical patients.

Introduction

The Robotic system allows to precisely plan operations and transfer the plans to the operation site, thus allowing simulation of the surgical outcome in advance and reach the desired goals. Till now, minimal invasive techniques have been avoided in head and neck surgery, because of concerns related to visualisation, damage to vital structures and limited availability to effective instrumentation. Efforts are being focussed to reduce trauma of such operations, which is marking the introduction of robot assisted surgery[1]. The term 'ROBOT' was derived from CZECH word Robota (slave labour) in 1921 by Karel Capek. Idea of Robotic surgery was first proposed by National Aeronautics and Space Administration (NASA) in 1972 for astronauts. NASA proposed the 2 key concepts: 1. the need to develop systems approach to the management of major clinical medical events in space. 2. the need to develop and evaluate appropriate hardware and techniques for performance of surgery in space[2]. The use of robots in the field of medicine started in 1985, since then robots have been used in Orthopaedics for total hip replacement, in urology for transurethral resection of prostrate, brachytherapy and interventional radiation therapy, endoscopy, laproscopy etc. Recently robots were used in Ortholaringorhinology for paranasal sinus surgery and for milling the bed for cochlear implant[1].

In oral and maxillofacial surgery, robotic technique is being used for milling of bone surfaces, drilling of holes, deep saw osteotomy cuts, selection of osteosynthesis plates, bending and intra-operative positioning in defined position[1], orthognathic surgery planning[3]. It is also being used to treat tongue based adenoid carcinomas. Open aggressive aforesaid surgeries which may have adverse effects on speech and swallowing lead to the application of robot assisted surgery in maxillofacial region[4]. Robots have a better three dimensional spatial accuracy, reliability and precision.[3] Basically, robots provide better visualization, controlled movements of armamentarium, efficient haemostasis and tissue dissection. Armaments

* *Corresponding author:* ***Dr Gourav Popli (Senior Lecturer) Department of Oral and Maxillofacial Surgery Subharti Dental college, Swami Vivekanand Subharti University Meerut Phone No:- +91 8475991147 Email id:- drgp0250@gmail.com***

can move in 360 degree angle beside the controlled and flexible reaction.[4] Beside these, certain disadvantages being encountered are high cost factors, long planning time and difficult automatization. In addition, there is no standard of safety recommendation and difficult coordination for interdisciplinary work between engineers and surgeons[1].

History

The term "Robotics" is derived from Greek word meaning Slave Labour or Forced Labour.[5,2] A Robot is " A reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or specialized devices through various programmed motions for the performance of a variety of tasks".[6] Surgical robots as defined by **Davis** as " A powered computered- controlled manipulator with artificial sensing that can be reprogrammed to move and position tools to carry out a range of surgical task".[7] First time introduced by the **Playwrighter Karel Capek** in year 1921, in his satirical drama **Rossum's universal robots** in which robots were designed to do the banal work.[5] In 1942, **Issaac Asimov** used the word Robotic in a short stort "Runaround". **Engelberg and George C. Devol** started the first commercial company to make Robots called **Unimation** (Universal Automation) based on the ideas of Assimov. Thus, Engelberg is called 'The Father of Robotics. In the year 1967, Versatron introduced the first Industrial Robot in Japan from American Machine and Foundary (AMF). In the following year, Kawasaki licenced the hydraulic Robot design from Unimation and started production in Japan, from that time onwards, Japan has become the Global Leader in the development and distribution of Robots of all types. According to the World Fact Book 2002, Japan possesses 4,10,000 of the worlds 7,20,000 working Robots.[6] In 1980s when George Bush announced his intentions on getting a man on Mars, the NASA began to fund proposals for the eventual needs for possible surgical intervention on Astronaut remote from a hospital. A team of investigators lead by Michael Mc Greevey and Stephen Ellis, became to investigate 19,861 computer generated scenarios that could be perceived on hard mounted displays (HMD). To this team, eventually came ScottFisher, who added 3 D audio and came up with a concept of "Telepresence". This was the motion that, one person could be projected with the immersive experience of another. The initial systems conceived that the Surgeon would be helmented immersive site/sound environment wired electronically to "Data gloves", that would digitally track the surgeon's motions and reproduce them at remote Robotic instrument. Later, the HMD were replaced with monitor and the data gloves were replaced with handles for controllers at the surgeon's console.[6] The first clinical trial was performed in April 1985 for the surgical Robots on a patient with suspicious brain lesion.[1] Programmable Universal for Assembly (PUMA) performed trans urethral prostatectomy successfully at Imperial College of London. First Robotic surgery on Prostrate was successfully performed in March 1991 in Shaftesbury Hospital Institute of Urology, London, UK, after which came the PROBOT- Robot for Prostratomies.[6] Advanced Robotic Telemanipulators for minimally invasive surgery (ARTEMIS) was developed in 1990. It was the first Robot with 6 degree of freedom for surgery, but the project failed because it could not gather continuous funding.[6] In 1993, Yulyn Wang from the University of California developed automated endoscopic system for optimal positioning (AESOP). Later, Imperial College of London further developed Urobot- surgeon programmable Urologic device. In 1997-2002, John Hopkins Medical Centre was involved in the development of Robotic system to perform percutaneous access to the Kidney. The device achieved an accuracy of 50% in live animal trials. In 1995-2002, came the most popular da Vinci surgical system, the device comprised of three main components a) A master slave software driven system that provided control of 7 degree of freedom. b) A 3-dimensional immersive vision system. c) A sensor based safety monitoring system to continuously reassess the device performance to maximise patient safety. The first prototype was tested in March, 1997 and by April, 1997, the first Robotic surgery by this system was performed.[6] In December, 2002, FDA approved the use of the next generation Da Vinvi System with the addition of fourth Robotic arm to the tower. The most recent Robotic surgical platform is Da Vinci type S Si system with high definition digital visual magnification, which allows for a greater magnification than the standard one. The high definition camera helped surgeon to position the camera 6-7 cm away from the operative field to avoid any local tissue effect from the heat emitted by the camera lightening.[6]

At present there are two group of Robots, the first group, the telemanipulators, which are not pre-programmed. The basic principle is that on a so called slave console, the movements of the surgeon, who is sitting at the master console and moving steering paddles are simulated. Steering console displays the endoscopic images directly on a monitor for the feedback of the surgeon. The other group of system, the pre-programmed surgical Robots, execute on a preoperatively defined trajectories. Nevertheless, the Robots are controlled by the surgeon during the whole operation and can be stopped at any time in emergency.[1]

Discussion

Initial work in craniofacial domain was done by **Weihe et al in 2000**, who evaluated the practicability of intra-operative instrument navigation and robotics for single step reconstruction of computer aided fronto-temporal bone resection. They designed two complex defects in fronto-temporal skull, resection of first defect was done with the help of template and the other was done by robot and they concluded that resection using a template had better precision and practicability.[8] Afterwards, **Terris et al In 2002** performed endo-robotic surgery on procine models and observed improved precision and efficiency for neck procedures. They observed advantages like 3D imaging, versality, flexibility, précised and co-ordinated procedure. Moreover, complications like pneumothorax and emphysema associated with cervical endoscopic surgery were surmounted.[9] Simultaneously **Engle et al in 2002** assessed the RobaCKa, a robot developed by IPR university for its accuracy in sensor milling in craniofacial surgeries associated with vital structures. They observed an accuracy of 1 mm from planning to execution as they counter balanced the micromovements of patients by simultaneous tracking with optical navigation system.[10] Later on, **Tamer Theodossy et al In 2003** compared model surgery in orthognathics performed by robots and manually on 21 patients and observed that model surgery performed with the aid of robotic arm was more accurate and precise in antero-posterior and vertical planes as compared to manual procedures.[3] **David Terries et al 2008** reviewed the use of endorobotic in neck dissection and submandibular gland resection. In their 2 cases of thyroidectomies with different approaches (supra-clavicular and axillary approach), they found that overall dissection was facilitated in limited space and 3-D view and lesser surgical time with endorobotics as compared to conventional endoscopy.[9] **In 2009 Auranuch et al** first introduced the robotic system to dental implants. They developed dental implant surgical navigation system based on homogenous transformation algorithms. With the help of CT and computer assisted surgery system, authors 1st assessed anatomy, and then intra-operatively 3-D images with real time monitoring. They designed high accuracy tracking system with infra red surgical marker emmiters and tracked movements of surgery and patients position. Implant was placed with a deviation of less than 1 mm and mean spatial error of navigation system of 0.35 mm.[11] Simultaneously **Gregory S. Weinstein** was working with da Vinci surgical robot and performed trans-oral robotic surgery (TORS) at university of Pennsylvania on 225 cases including partial laryngectomies, selective neck dissections and submandibular gland ablations. They found TORS to be beneficial as it provides better visualisation and assess to tumors via minimally invasive, less morbid approach, resulting in overall functional outcome and discussed there results in English literature in 2009.[12] **Ryan R. MC Cool et al in 2010** performed a cadaveric study to assess feasibility of robotic dissection of the infra-temporal fossa using a novel, midline suprahyoid port procedure. They performed six complete and two partial dissections of infra-temporal fossa using da Vinci surgical robot. They commented on the promising advantages of robotic surgery in skull base region over open and endoscopic techniques.[13] **William I. Wei in 2010** performed transoral robotic nasopharyngectomy in a patient with recurrent nasopharyngeal carcinoma. They used split palatal approach and exposed entire nasopharynx followed by removal of pathology using two robotic arms along with camera. Final prognosis of the reported case indicated the usefulness of robots for pharyngeal carcinomas.[14] **Rohan R Walvekar et al in 2010** presented the first surgical description in world literature for use of surgical robots for the removal of salivary stones. They used the da Vinci Si surgical system to facilitate a trans-oral Sialolithotomy in conjunction with Sialoendoscopy. Total time of surgery was around 120 minutes and they observed usefulness of da Vinci surgical system with excellent visualization, magnification and dexterity for trans-oral stone removal with preservation of the lingual nerve and submandibular duct.[15] **John Martell et al in 2011** advocated that lack of tactile feedback was one of the limitation with robotics. So, they incorporated a high resolution binocular vision and used the visual clues as a surrogate for sensory feedback. They calculated the suture strain by visually observing the deflection of the membrane being manipulated. This real time feedback of suture tension is expected to compensate for the current lack of sensory feedback in robotic surgery.[16] **Dallan et al in 2011** enumerated the limitations of robotic surgery in head and neck region. They noticed narrow areas of work and thus recommended that arms of the system should work parallel to one another to avoid conflict. They also commented on the advantages of robotic skull base surgeries which included frameless neuronavigation, modular approaches, and intra-operative imaging systems etc.[17]

Prem N Kakar et al in 2011 commented that the major obstacle to the telerobotic surgery is “Latent Time”, which the time is taken to send an electric signal from hand motion to actual visualisation of hand motion on a remote screen. They introduced an anaesthesia robot called “Mc Sleepy” at Montreal’s Mc Gill university that can act as an anaesthologist. It can analyse biological information, can constantly adapt its own behaviour and even recognize monitoring malfunction.[7] **Ronal B. Kuppersmith et al in 2011** applied the robotic surgical technology to thyroid surgery and yielded new approaches that were less invasive for thyroid gland removal. For the aforesaid purpose, they applied the da Vinci surgical system and approached through a 5-6 cm incision in the anterior aspect of ipsilateral axilla. They commented that the rationale for this approach was the improved cosmetic outcome with elimination of a neck incision.[18] **Samuel A Dowthwaite et al in 2011** reviewed the role of Transoral Robotic Surgery for treatment of Head and Neck Malignancies, particularly for Orapharyngeal squamous cell carcinoma (OSSC). They felt that the promising impact of TORS on the quality of life and surgical outcomes of OSSC would require high level of supporting evidence.[19] **Rohan R Walvekar et al in 2011** reported the case of the resection of Bilateral Oral Ranulas by Robotic technology. They used da Vinci system for the management of ranulas, which helped them in preservation of the lingual nerve and Wharton’s duct with good functional outcomes with total procedure time of 44 and 59 minutes for right and left side respectively. However, they commented that long term results and cost effectiveness of robotic systems need further validation.[20] **Fatma Tulin Kayhan et al in 2011** reported the role of Transoral Robotic Surgery for Tongue based Adenoid Cystic Carcinoma. They encountered a case of ACC measuring 4.6x5x 5.5 cm and extending from the tongue base upto the epiglottic petiole. Since, the open surgery would have had the adverse effects on speech and swallowing, so, they opted for the TORS, which helped them in maintaining the postoperative quality of life.[4] **Indran Balasundaram et al in 2011** reconstructed the complex fractures of zygoma and orbital floor with the help of Navigation system. They also described a case series of five patients who had resection of oropharyngeal tumours, reconstruction, and microvascular anastomosis with the da Vinci Robot without requiring a mandibulectomy. They concluded that the TORS is an effective way to preserve the mandible, and also allowed superior visualisation, access, and precision in areas that were normally very challenging technically.[21] **Samuel Robinson et al in 2012** performed the Robot assisted volumetric tongue base reduction and pharyngeal surgery for Obstructive sleep apnoea. They described a perioral robot assisted technique that removed the midline tongue musculature via a dorsal mucosal incision. This mucosa sparing tongue volume reduction surgery performed trans-orally provided a low morbidity and relatively pain free approach. They reviewed that da Vinci robot is an excellent surgical tool for OSA surgery.[22] **Park YM et al in 2013** analysed the oncologic and functional outcomes of trans-oral robotic surgery in cases of oropharyngeal carcinomas. They treated 39 patients of oropharyngeal cancer by TORS. They observed acceptable results of TORS for oropharyngeal cancer, and found it bo be suitable minimally invasive treatment for selected patients.[23] **Hyoung Shin Lee et al in 2014** compared the clinico-pathological results of robot assisted and endoscopic resection of the submandibular gland by retro-auricular approach. They studied 35 patients for submandibular gland resection and observed no difference in the clinical outcomes in both groups. Both groups showed comparable early surgical outcomes and excellent cosmetic results. They concluded that despite the technical convenience for the surgeon, robots gave no apparent clinical benefit over the endoscope.[24] **Tsung-Lin Yang et al in 2014** investigated the efficacy of gland preserving robotic surgery using a hairline approach. They compared robotic with open techniques for gland preserving operations to remove benign tumours of the submandibular gland. They included total 8 patients in their study and observed no postoperative complications or nerve deficit and aesthetically pleasing outcome in robot surgery group.[25] **Kawaguchi et al in 2014** performed Image guided robotic stereotactic radiotherapy in a patient with synchronous cancer of maxillary gingival and lung. They used CyberKnife system and treatment included fiducial gold pins implanted using bronchoscopy. They observed limited toxicity and no recurrence at 2 year follow up.[26]

Limitations of Robotic Systems

Robots have few limitations such as unwieldy nature of robotic systems requires considerable space and additional time and personnel's for setting it up. Also, the bulkiness precludes its use in other head and neck areas such as otology and trans-nasal procedures. Cost barrier is a major issue to put this technology to routine use. The initial cost of installation of a single unit is approximately 1.5 million dollars along with 1 lakh dollars annually on maintenance and 200 dollar per case of disposable instruments. Although results, show that learning the art of robotic surgery is easy but safety concern is a challenge for robot manufacturers. Though, early experiments performed with TORS demonstrates safety profile similar to conventional surgical instruments. Lastly lack of tactile feedback is a major limitation, required to be addressed in the near future.[27]

Conclusion

Robotic surgery had started a new era of tele-surgery. The present outlook of this subtle technology has certainly captured the surgeon's quest to avail the least invasive methods. Given the primary results, from the patient's perspective also, its adoption in near future is inevitable. Till the time we need to work diligently as a team to draw long term results to convince or silence the critics of robotic head and neck surgery. The Oral and Maxillofacial surgical procedures are complex and have potentially significant immediate postoperative morbidity and risk of mortality. It is, therefore, important that patients are evaluated and pre-planned carefully and there is an immense need of following the same trajectory of preoperative planning to the patient in operation theatre. The latest robotic system, da Vinci robot is an excellent surgical tool for oral surgery, it provides excellent visual access, tremor free instrumentation and easy access for an assistant surgeon.

Thus, surgery can be performed safely, efficiently, and with ease.

Besides many of the benefits they are not being used in routine surgery as each patient is individual and in each surgery some unexpected situations can happen, for which robots cannot be pre-programmed, so total automation is not desired or possible and surgical robots will always work in cooperation with the surgeon and cannot substitute them. Furthermore, so far there is no general standard of safety recommendation for medical robot devices either. They have to be smaller and more suitable for operating room. Another problem is the preoperative planning, which takes much time and is not desired in routine clinical work. Therefore, new concepts for computer assisted surgeries rely on intraoperative planning. One of the main challenge is still the interdisciplinary work of engineers and surgeons, which have to find to a common language.

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