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Research Paper

Robotics in Oral and Maxillofacial Surgery - A Review

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ABSTRACT:
Throughout the twenty-first century, robotic surgery has been used in multiple oral surgical procedures for the treatment of head and neck tumors and non-malignant diseases. With the assistance of robotic surgical systems, maxillofacial surgery is performed with less blood loss, fewer complications, shorter hospitalization and better cosmetic results than standard open surgery. However, the application of robotic surgery techniques to the treatment of head and neck diseases remains in an experimental stage, and the long-lasting effects on surgical morbidity, oncologic control and quality of life are yet to be established. Maxillofacial surgeries are being performed with large incisions, either via a transmandibular or a transpharyngeal approach, because of anatomical complications and minimal surgical space. These procedures typically result in significant surgical morbidity, speech dysfunction and dyspepsia from the dissection of large amounts of normal tissue. Robotic surgical system allows surgeons to access tissue throught a few small incisions instead of a large incision. The focus of these procedures is now on preserving function, reducing postoperative morbidity and improving quality of life. Robotic surgical systems will inevitably be extended to maxillofacial surgery.
Conclusions: *Robotic surgery in the oral and maxillofacial region allows the incision to hide the scar by making the incision line far from the surgical field, resulting in fewer intra-operative and post-operative complications, such as amount of drainage or hospital days. Furthermore, recent studies show similar or superior results in terms of oncologic safety of robot assisted surgeries compared to conventional surgeries.*
Keywords: *Head and neck, maxillofacial surgery, oral surgical procedures, robotic surgery*

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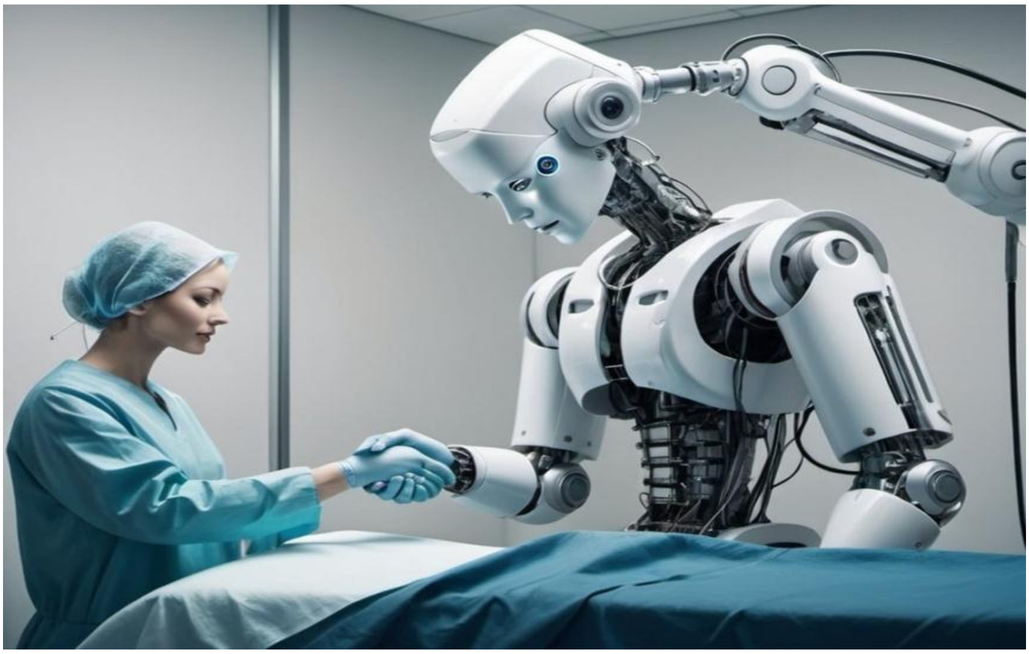
ROBOTICS IN OMFS – A REVIEW

I. INTRODUCTION:

The use of robotics in oral and maxillofacial specialty is also in its infancy. It is unlikely robotic technology will be able to completely replace direct human involvement in oral-maxillofacial surgical procedures. But robot assisted surgery is already here and growing in usage. In this case, the robot, when combined with imaging and AI, can “see” anatomy the surgeon is unable to visualize and provide haptic guidance to the surgeon, lessening the chance of mis-directed drills, saws, and other cutting tools, thereby improving surgical precision and patient safety. Since the robot-assisting technology can provide guidance, there is less need for wide surgical exposure, opening more procedures to a minimally-invasive approach. Innovations may come where the surgeon uses a joystick, mouse, or virtual reality gloves to be able to conduct certain procedures remotely through robotics with the patient or help guide a distant surgeon through procedures. Efforts have continued to be made toward minimally invasive surgery (MIS), with head and neck surgery requiring incisions which will leave long visible scars to be used to approach the lesion. However, due to the difficulty in ligation of neurovascular structures, visualization of surgical fields, and proximity of anatomical critical structures, only recently have there been significant advances in minimally invasive techniques as applied in oral and maxillofacial surgery.[1]

A series of attempts to achieve MIS were made using endoscopy, but was not so easy to operate. Robotic surgical systems can address these shortcomings, the use of robots in head & neck and maxillofacial surgery has recently become more common.[2]

Taking inspiration from its use in other surgical fields, the benefits to surgeons include a three dimensional magnified view, precise movements, bimanual operation with articulated arms and suppression of tremor, which enhances the surgeon's physical capabilities. Thus, procedures with robotic assistance can be performed with less blood loss, fewer complications, shorter hospital stays and better cosmetic results than standard open techniques robotic surgery may hold promise in the treatment of craniofacial conditions, such as head and neck neoplasms, cleft palate and craniofacial asymmetry, among others.[3]



HISTORY OF ROBOTIC SURGICAL SYSTEM:

The first model of the robotic arm approved in 1994 for usage, the AESOP 1000, was controlled using pedals. Its future generation, the AESOP 2000 designed 2 years later, replaced the pedals with a voice control system, allowing the surgeon to have control of the endoscope, providing a ‘‘third hand”. By using its voice, the AESOP 2000 eliminated the necessity of an assistant to hold the endoscope. The platform evolved to AESOP 3000® increasing the degrees of freedom, and had its final platform with the AESOP HR (HERMES Ready), having integrated voice control and functions such as operating room lighting and movement of the operating table. When idealized, the robotic AESOP was designed to improve image stability and reduce the medical personnel required in the operating room, showing numerous documented advantages over traditional human-assisted camera holding, especially replacing the need for a surgical assistant who may become fatigued during long procedures . Not completely satisfied, however, the surgical procedures demanded not only the concept of telemanipulation of the video camera but also surgeons’ movements.[5,6]

AESOP robot

Application of AEESOP in minimally invasive surgery

Computer Motion, in 1998, presented the Zeus system with arms and surgical instruments controlled by the surgeon, introducing the actual concept of telepresence, in which the surgeon (master) commands the slave (robot). The ZEUS robot consisted of three arms, each independently attached to a surgical table, having one AESOP arm controlling the scope and two other surgical arms with four degrees of freedom. The surgeon console consisted of a video monitor and two handles which are able to manipulate the instruments, providing an enhanced interface and 2-dimensional display. The ZEUS robotic platform was used for the first time in 1998 at the Cleveland Clinic for uterine tube anastomosis surgery.[7,8]

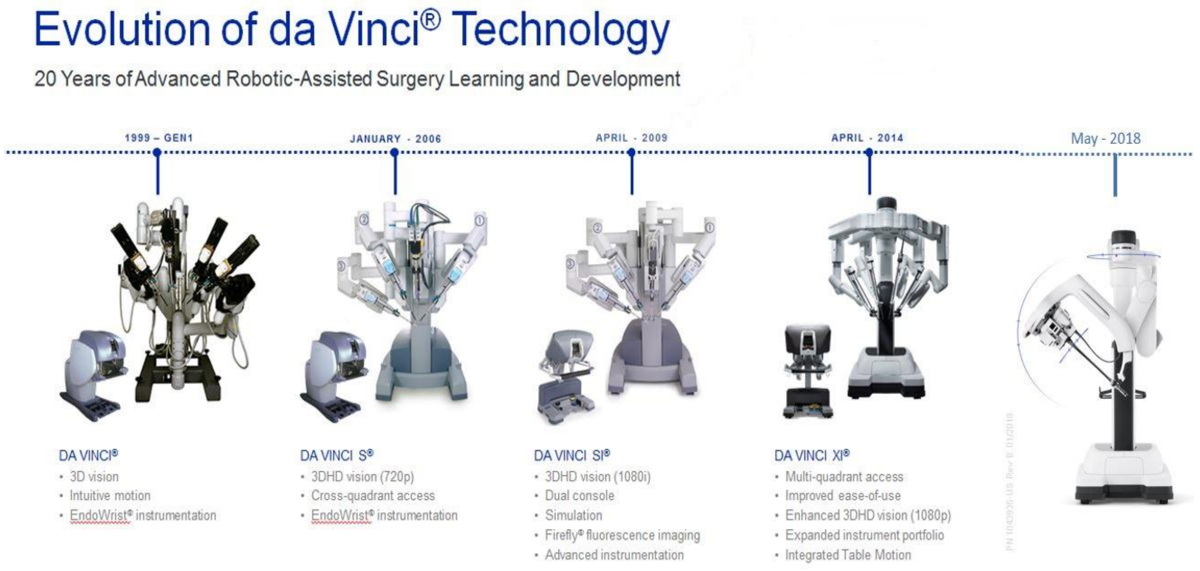
In 2000, the da Vinci obtained FDA approval for general laparoscopic procedures and became the first operative surgical robot in the United States (US).

In 2003, following a 3 year legal battle, the Computer Motion merged with the Intuitive Surgical into a single company, discontinuing the development of the ZEUS system. Both companies combined the efforts having many of its elements integrated with later projects in producing a more effective technology.[9]

Compared to the ZEUS platform, the Intuitive's next generation system, da Vinci, improved significantly on the previous prototypes. The robotic system was composed of 3 components, with a patient cart, a surgeon console and the image system. All robotic arms originated from a single patient cart, which obviate the need to mount each arm to the operating table and solved issues with table positioning. With seven degrees of freedom and two degrees of axial rotation, the surgical instruments imitate the human wrist. The surgeons console with an image system brought to da Vinci robot a completely innovative manner to connect the surgeon with the stereoscopic viewer, having a binocular visualization trademark. Instead of a video display, the viewer was placed in the surgeon console where both eyes were accommodated allowing greater focus and concentration, reducing fatigue during surgery. By using a new 3D endoscope, the use of two 5mm scopes inside the 12mm telescope, the image was projected onto two screens synchronized and creating a truly 3D visualization without the necessity of using specific goggles. The first da Vinci robot approved by the FDA in 2000 was composed of three arms with endoscope attachment to one of them and two instruments. [10,11] Two years later, in 2002, foreseeing the necessity and value of an extra instrument in the surgical field, a four-arm robotic version was approved for clinical use. This arm would give the possibility of controlling and improving the exposure of anatomical structures and reducing dependence on a surgical assistant. At the console, two handles controlled by the surgeon were precisely connected to the arms transmitting the movements of the “master” to the robotic arms. Hand tremors were eliminated and a device that scales down movements from 1:1 to 5:1 allowed finesse according to the surgeons’ necessity. Also, the console had in its bottom a pedal unit to allow different uses of energy, such as monopolar or bipolar.[13]

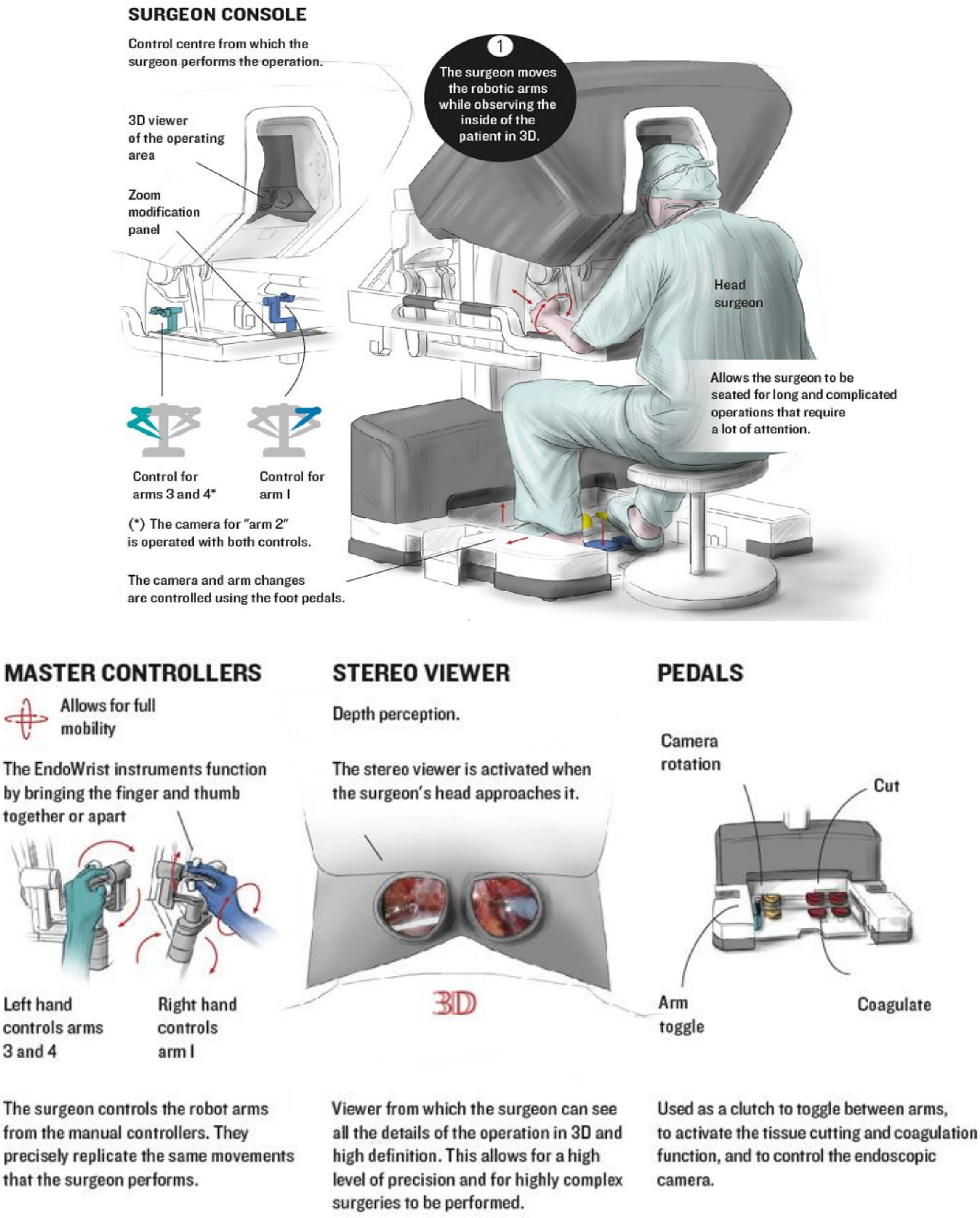
Not completely satisfied with the first prototype, Intuitive Surgical introduced in 2006 the da Vinci S platform offering a 3D high-definition (HD) camera vision with a simplified set-up and an interactive touch screen display. Three years later, in 2009, the da Vinci Si model was released becoming what could be one of the most worldwide disseminated platforms since its creation .[15] The new Si platform offered the concept of dual console surgery, optimizing the surgeon’s potential intraoperatively as well as introducing a reproducible and supervised manner of simulation and training for non-expert surgeons. Also, the Si robot had an upgrade of the image system to the incorporation of the Tile-Pro software, and it allowed real time fluorescence imaging with the Firefly technology, playing an important role in its promulgation for minimally invasive surgery. Still, in 2011, platform adjustments and specific instruments were developed to allow a single-port access, overcoming laparoscopic limitations.[14]

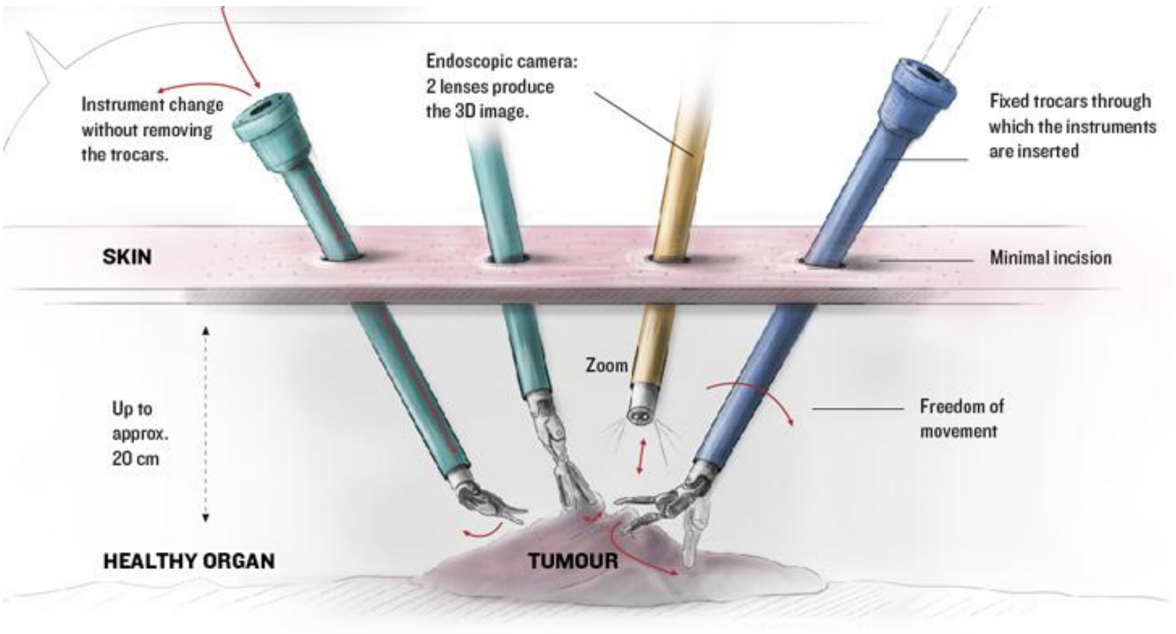
The most capable system created by Intuitive Surgical until is now the da Vinci Xi platform. Its release occurred in 2014, entering the market as the most advanced instrumentation, vision, cart design, as well as table motion and setup automation . Looking at a different perspective, the Xi latest model reinvented the concept of the patient cart design and its versatility and flexibility. Although impressive, the Si platform and its upgrades were not without its limitations. The robotic arms in the patients’ cart were large, making them troublesome to work and frequently leading to external collisions.[15]

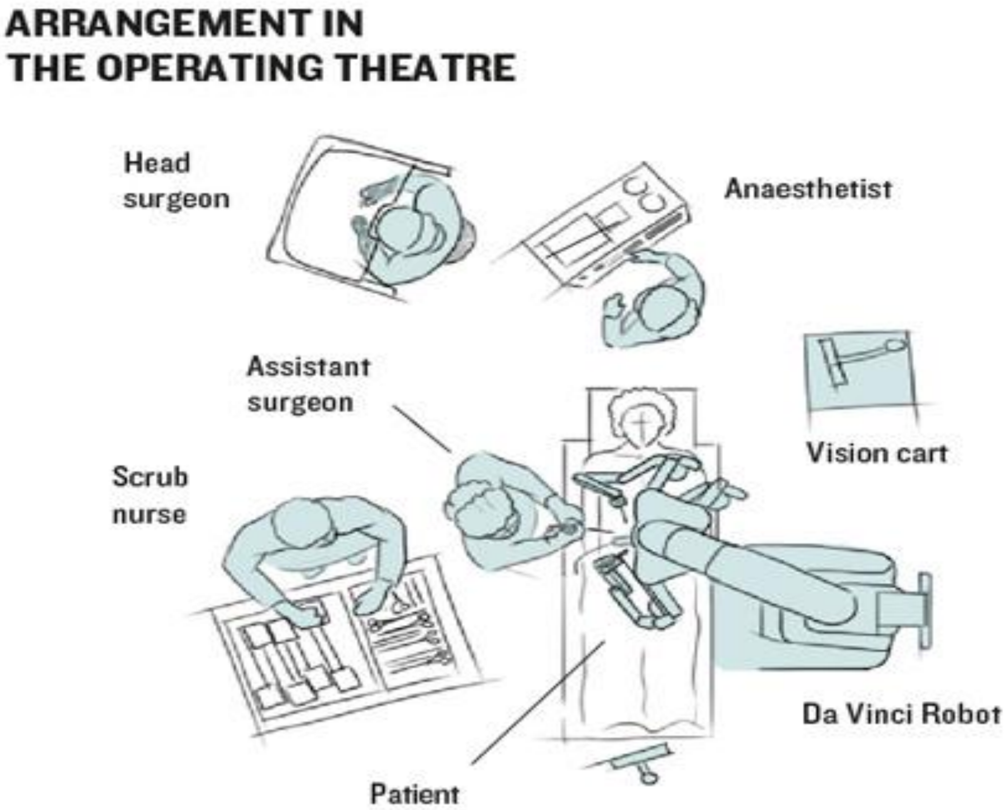


PARTS OF ROBOTIC SYSTEM:

1 **.Surgeon's Console**: The control station where the surgeon sits and operates the robotic arms. It provides a magnified, 3D view of the surgical field.
2. **Robotic Arms:** Equipped with surgical instruments that mimic the surgeon's hand movements with precision.
3. **Vision System**: High-definition cameras that provide detailed, real-time views of the operating site.
4. **Patient-Side Cart**: Holds the robotic arms and positions them for surgery.[18]


SURGEON CONSOLE
Control centre from which the surgeon performs the operation.
1
The surgeon moves the robotic arms while observing the inside of the patient in 3D.
3D viewer of the operating area
Zoom modification panel
Head surgeon
Allows the surgeon to be seated for long and complicated operations that require a lot of attention.
Control for arms 3 and 4*
Control for arm I
(*) The camera for "arm 2" is operated with both controls.
The camera and arm changes are controlled using the foot pedals.
MASTER CONTROLLERS
Allows for full mobility
The EndoWrist instruments function by bringing the finger and thumb together or apart
Left hand controls arms 3 and 4
Right hand controls arm I
The surgeon controls the robot arms from the manual controllers. They precisely replicate the same movements that the surgeon performs.
STEREO VIEWER
Depth perception.
The stereo viewer is activated when the surgeon's head approaches it.
3D
Viewer from which the surgeon can see all the details of the operation in 3D and high definition. This allows for a high level of precision and for highly complex surgeries to be performed.
PEDALS
Camera rotation
Cut
Arm toggle
Coagulate
Used as a clutch to toggle between arms, to activate the tissue cutting and coagulation function, and to control the endoscopic camera.





CLINICAL APPLICATION OF ROBOTICS IN OMFS:

Currently, the chief indications for robotic surgery in the head and neck region are removal of head and neck neoplasms or cysts that can be sufficiently exposed via a robotic approach; (2) therapeutic and selective neck dissection; and (3) obstructive sleep apnea syndrome (OSAS). Meanwhile, tumors with jaw or internal carotid artery invasion are not currently suitable for robot-assisted resection.[20]

Head and neck neoplasms:

Head and neck neoplasm is a group of neoplasms that arise from the oral cavity, pharynx, larynx, sinuses or salivary glands, among others. Oral cavity cancer has the highest incidence of the head and neck cancers and is increasing in incidence. surgery can be particularly difficult if the tumor is near the larynx, which might result in dysphasia. Of these surgeries, robotic surgery allows the surgeon to remove tumors with minimal damage to normal tissues, and it gives patients as much speech and swallowing function as possible postoperatively. [25]

Oral cavity, Oropharynx, Nasopharynx and Laryngopharynx:

Weinstein and colleagues successfully performed a robot-assisted radical tonsillectomy in 2007 after cadaveric robotic surgery. With this much groundwork completed, several studies subsequently focused on the application of TORS in various types of neoplasms, including squamous cell carcinoma, mucoepidermoid carcinoma, malignant melanoma, synoviosarcoma, adenoid cystic carcinoma, pleomorphic adenoma, lipoma and neurilemmoma. Several studies have demonstrated that robotic surgery for primary or recurrent neoplasms in the oral cavity, oropharynx, nasopharynx and laryngopharynx has superior functional recovery; higher rates of negative margin, recurrence-free survival, disease-free survival and overall survival; and a lower risk of hemorrhage, gastrostomy tube and tracheostomy tube dependence, and other intraoperative or postoperative complications than conventional open surgery or radiochemical therapy. However, it is also worth noting that Blanco et al. reported an application of TORS in the treatment of recurrent oropharynx squamous cell carcinoma, in which three of four patients experienced postoperative regional or distal transference. Furthermore, TORS appeared to be more effective in the detection and diagnosis of unknown primary tumors than conventional methods, including computed tomography, positron-emission tomography and directed biopsies, especially for human papillomavirus (HPV)-positive patients. [29]

Parapharyngeal space.

The parapharyngeal space is a potentially deep and anatomically compact space in the head and neck that contains important anatomic structures. O'Malley and Weinstein first performed robot-assisted resection of a benign neoplasm in the parapharyngeal space based on cadaveric and animal robotic surgery. Several subsequent reports showed favorable results, such as short hospital stays, quick functional recovery and a lack of significant complications, when parapharyngeal neoplasms (squamous cell carcinoma, lipoma, pleomorphic adenoma, adenoid cystic carcinoma, cartilaginous tumor and neurilemmoma) were removed using the robot.[28,30]

Thyroid gland and mediastinal parathyroid.:

Bodner et al. described the first use of a robotic surgical system for mediastinal parathyroid resection via a transaxillary incision in 2004 and showed that transaxillary robotic surgery is a minimally invasive, effective and safe procedure. Lingual thyroglossal duct cyst was also excised using a robotic surgery system via a transoral approach or a retroauricular approach without complications or recurrence. Traditional surgery was always associated with an undesirable scar in the neck and a high relapse rate. In Kim et al. opinion, the 3-dimensional, magnified visualization of the robot resulted in less damage to the surrounding normal tissues, reduced intraoperative bleeding and infection, and the ability to ligate the tract after carefully tracing it.[32]

Salivary glands:

Submandibular gland tumors were traditionally excised via a transcervical approach, which always left a visible scar, and possibly even hypertrophic scarring in the neck. In comparison, on the basis of its guaranteed curative effect, robotic resection of the submandibular gland through a retroauricular approach or modified face-lift approach can produce an invisible scar, making it more acceptable to patients. The study by Yang et al. showed that gland-preserving robotic surgery has a potentially lower risk of intraoperative hemorrhage, positive margins and postoperative functional nerve deficit than conventional transcervical surgery.[34]

Neck dissection:

Neck dissection followed by head and neck tumor removal is always necessary to reduce locoregional recurrence. Kang et al.96 first applied a robotic surgical system in a radical neck dissection via a transaxillary track for the staged treatment of thyroid carcinoma to avoid a long visible incision scar and muscle deformities in the neck area as well as to strengthen deep and corner dissections.[35]

Post-ablative defect reconstruction:

The first use of a robotic surgical system in post-ablative defect reconstruction was reported by Genden et al. in which a mucosal advancement flap, two pyriform mucosal flaps and three posterior pharyngeal wall flaps were performed. Since then, the robotic surgical system has been increasingly employed in head and neck defect reconstruction. Various flaps, including a mucosal muscle flap, radial forearm flap and free anterolateral femoral skin flap, were applied for reconstruction. The studies mentioned above also showed that robotic reconstruction surgery has a shorter operative time, better functional recovery and more satisfactory aesthetics than conventional surgery.[35, 33]

Cleft lip and palate:

Currently, the use of robotic surgical systems in the treatment of cleft lip and palate is still in an early stage of development. Khan et al.110 first reported the theoretical feasibility of robotic intra-oral cleft surgery and Hynes pharyngoplasty in a pediatric airway manikin and human cadaver in 2015. In the same year, Nadjmi demonstrated the technical feasibility and safety of robot-assisted soft palate muscle reconstruction in 10 consecutive patients (mean age: 9.5 months) with palatal clefts after cadaveric TORS. The results showed that the surgical duration of TORS is much longer than conventional surgery; however, the hospital stays and functional recovery for the robotic approach were significantly shorter than for the manual approach. Nadjmi believed that this was because of the precise dissection provided by the robotic surgical system, which might reduce damage to the vascularization and related innervation of surrounding muscles.[[37]

Craniofacial asymmetry:

The theoretical feasibility of robot-assisted orthognathic surgery was proposed in 2010 by Chen et al. who suggested a method using the six degrees of freedom robot MOTOMAN to perform bone cutting and drilling based on the navigation system that they programmed. Later, Peking University developed a robotic surgical system for the design of orthognathic surgery, bone reconstruction and intraoperative navigation. However, the clinical application of robotic orthognathic surgery has not been reported, and the robotic surgical system mentioned above remains in an experimental stage.[38]

OSAS:[**OBSTRUCTIVE SLEEP APNEA SYNDROM**]

Vicini et al.reported the first application of TORS in the resection of the BOT, combined with conventional septoplasty, UPPP or supraglottoplasty, for OSAS patients in 2010 without any intraoperative and postoperative complications. The result showed a similar surgical duration to open surgery. No tracheotomy was required during surgery, and all patients had an excellent functional recovery. The postoperative Apnea–Hypopnea Index (AHI) and Epworth Sleepiness Scale (ESS) were significantly decreased from their preoperative values, and 90% of patients were satisfied with the results. Subsequently, TORS[trans oral robotic surgery] became widely applied for OSA sufferers for tonsillectomy, supraglottoplasty and glossectomy.[37]

Laryngocele:
Ciabatti et al. used TORS for the excision of a large mixed laryngocele with short operative time and satisfactory aesthetics. No complications were observed, and an oral diet was started 1 day postoperatively and the patient was discharged 2 days after TORS.[39]

Ectopic lingual thyroid:
In May 2011, robot-assisted dissection of a lingual thyroid gland in three patients with minimal morbidity and excellent functional outcomes was successfully performed. Recently, an increasing number of ectopic lingual thyroids have been excised via a robotic surgical system. The results showed that patients undergoing TORS could start oral feeding on the first postoperative day, and no recurrence was observed within 2 months of follow-up.[38]

Ptyalolithiasis:
Walvekar et al. first reported the successful removal of a 20-mm submandibular megalith and the subsequent repair of the salivary duct using a robotic surgical system. The total time involved was 120 min, and no complications were noted. Recently, Razavi et al.facilitated large submandibular gland stone removal using TORS in 22 patients. Procedural success was 100%, and no symptoms of recurrence or lingual nerve damage were recorded at follow-up.[40]

Vascular lesions:
Recently, the excision of BOT vascular lesions via a robotic surgical approach was described by Dziegielewski et al who found that it could be used in a safe manner to dissect BOT vascular lesions with maximum preservation of the surrounding vessels, nerves and muscles. Consequently, the postoperative damage to swallowing and speech function is minimal.[40]

Dental implant:
Robotic guidance in dental implant surgery provides several benefits. Firstly, the robotic arm offers haptic feedback, allowing physical guidance when placing the implant in the desired position. Secondly, a patient tracker integrated into the robotic system monitors patient movement and provides real-time feedback on a screen. This feature ensures that the surgeon is aware of any changes and can adjust accordingly. Dental implant robots offer improved precision, efficiency, and stability, enhancing implant accuracy and reducing surgical risks. Accurate placement of dental implants is crucial to avoid complications during and after surgery.

Supiriority of robot-assisted surgery:

Robotic surgery is typically minimally invasive. So the patient suffers less pain, slight blood loss and minimal scarring, and requires only a short recovery time. With the robotic arm eliminating the natural limits of human wrists, surgery can be performed with more delicate, precise and efficient movements. The 3D imaging and endowrist technology of robots ensure surgery is more accurate, nerve bundles are dissected more precisely, erectile function is preserved, and there is a better chance of cure than with non-robotic surgery. The surgeon also enjoys more strength, dexterity, flexibility, control and a better view of the operated area. Robotic surgery allows the surgeon to get more comfortable, perform the procedure with increased concentration and focus, and can undertake complex procedures that are tougher or impossible.[40]

Limitation of robot assisted surgery:

With robot-assisted surgery, there is not only the risk of human error when operating the robotic system, but also the potential for mechanical failure. For instance, system components such as robotic arms, camera, robotic tower, binocular lenses and instruments can fail. In other cases, the electrical current in the robotic instrument can leave the robotic arm and be misapplied to surrounding tissues, resulting in accidental burn injuries. Likewise, robot-assisted surgery can cause nerve palsies due to extreme body positioning or direct nerve compression that may occur when using robots. It also takes longer to perform robotic surgery than non-robotic surgery in surgical centers with lower robotic volume or by less experienced surgeons.[40]

Legal/Ethical issue in Robotic surgery:

- Time lag between surgeons commands and action of robot could harm the patient
- Loss of power in an electrical failure
- Robotics does not replace human intelligence, skill and experience
- Surgicals Robots are much costlier

II. Conclusion:

Robotic surgery may reduce operative morbidity, hospital stay and recovery while potentially improving clinical outcomes. The primary outcomes of robotic surgery in the head and neck region demonstrate good disease control, quick postoperative functional recovery and low surgical morbidity. However, definitive recommendations for the application of robotic surgical systems in the treatment of head and neck tumors, cleft lip and palate, OSAS and other conditions will require more well designed studies and technical modifications in current surgical robots and in the future.[40]

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