Head and neck robotic surgery: pros and cons

KH Kim¹ *, HG Choi², YH Jung²

Abstract
Robotic surgery was introduced to the head and neck area in 2005, following urological, gynaecological and cardiothoracic robotic procedures. It has subsequently become very widely used. We review the pros and cons of robotic surgery, along with the development history focusing on head and neck procedures. While continued refinements to robotic surgery will likely overcome its present limitations, patients need to be apprised of the current limitations as well as the evidence regarding its technical and oncological safety.

Introduction
Technological developments of robotic surgery are disseminating through every field of medicine. Robots are being utilized in urology, cardiology and gynaecology surgeries with great success¹. Over 65% of radical prostatectomies in the United States are being done robotically². The use of robots in head and neck surgery has become relatively common in recent years, and the number of robotic surgeries is growing. In my hospital, the da Vinci Robot system has been used since May, 2008. By the end of 2012, 2158 robotic surgeries had been performed, most commonly thyroid surgery (n = 1025) followed by prostate surgery (n = 856). As yet, few cases of transoral robotic surgery (TORS) or other head and neck robotic surgeries have been reported.

With the burgeoning use of robotic surgery and the collective history of prior cases, it is an appropriate time to consider the benefits and drawbacks—the ‘pros and cons’—of robotic surgery. This review summarizes the development, benefits and limitations of robotic surgery. Also, looking ahead, we propose a way of overcoming the current limitations.

Method
We performed a broad search in Medline and PubMed databases of the published data reporting robotic surgery in the head and neck area. Searches were restricted to the English language. The search terms were ‘robot’, ‘robotic’, ‘robotic surgery’, ‘TORS’, ‘robotic thyroid surgery’ and ‘robotic head and neck surgery’. Publications related to the clinical performance of robot-assisted head and neck surgery including thyroid surgery were included. Preclinical studies and non-clinical review articles were excluded. As there are few articles directly criticizing robotic surgery, we reviewed the identified articles to clarify the advantages and disadvantages of head and neck robotic surgery.

Results
The search terms yielded the following number of articles: 5754 for ‘robot’, 15276 for ‘robotic’, 4973 for ‘robotic surgery’, 133 for ‘TORS’, 113 for ‘robotic thyroid surgery’ and 159 for ‘robotic head and neck surgery’. A more refined search encompassing the past 5 years revealed the following numbers: 3390 for ‘robot’, 8424 for ‘robotic’, 3253 for ‘robotic surgery’, 122 for ‘TORS’, 106 for ‘robotic thyroid surgery’, and 126 for ‘robotic head and neck surgery’. Most reports concerning head and neck surgery were located using the search terms ‘trans oral robotic surgery’, ‘robotic thyroid surgery’ and ‘robotic head and neck surgery’, and these had been published within the past 5 years. In other words, head and neck robotic surgeries are still in the pioneering phase.

History
Leonardo da Vinci developed one of the first known robots—a mechanical armoured knight that was used to amuse royalty—in 1495. After his invention, steady and persistent efforts have been made to develop robots, which nowadays supplement or completely replace human labour—either automatically or manually.

Robots are used in the field of medicine for a variety of uses. One use is in rehabilitation medicine to help disability. As an example, Dr. David Gow created the first bionic arm in 1998. The Edinburgh Modular Arm System was created as a mobility aid for those lacking arms. The first surgical application of a robot was in the neurosurgical procedure for biopsy with Puma 560 in 1985³.

The current iteration of robots for surgery originated with a robot devised in the 1970s by the National Aeronautics and Space Administration (NASA) for the treatment of orbiting scientists⁴. It was conceived as a surgeon-controlled robotic hand piece and as an extension of NASA-developed virtual reality. The technology was refined as part of research conducted by the Defense Advanced Research Projects Administration with the aim of performing battlefield surgeries on wounded soldiers⁵. The 1990s witnessed the development of the da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA) and Automated Endoscopic System for Optimal Positioning (AESOP; Intuitive

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The first surgical use of robots in neck surgery. The US Food and Drug Administration (FDA) approved the da Vinci surgical robot in 2000 and has recently received approval for use in head and neck surgery. Of these, the da Vinci surgical system (Computer Motion, Goleta, CA) has become the most widely used and has recently received the US Food and Drug Administration (FDA) approval for use in head and neck surgery. Minimally invasive approaches have been avoided in head and neck surgery owing to concerns about visualization, possible damage to vital structures and the limited availability of effective instrumentation. The limited space available in regions such as the abdominal or pelvic space in the head and neck hinder the use of gas insufflation of the neck, which could induce complications such as pneumothorax. The first surgical use of robots in the head and neck area was in 2005. McLeod and Melder excised a vallecular cyst using the da Vinci surgical robot. In this surgery, only two of the three arms could be positioned in the operative field due to the size of the robot arm; the total operation time was 109 min, with 89 min spent in setup. Since this pioneering surgery, many clinical studies on robotic surgery in the head and neck area have been reported (Table 1).

### Table 1. Publications introducing novel application of robotic surgery in the head and neck area

<table>
<thead>
<tr>
<th>Authors</th>
<th>Anatomic regions/Name of procedure</th>
<th>Year</th>
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<tbody>
<tr>
<td>McLeod et al.</td>
<td>TORS for a vallecular cyst</td>
<td>2005</td>
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<tr>
<td>O’Malley et al.</td>
<td>TORS for base of tongue</td>
<td>2006</td>
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<tr>
<td>Tanna et al.</td>
<td>Thymus and thyroid surgery</td>
<td>2006</td>
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<td>Weinstein et al.</td>
<td>Supraglottic partial laryngectomy</td>
<td>2007</td>
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<tr>
<td>Weinstein et al.</td>
<td>Radical tonsillectomy with TORS</td>
<td>2007</td>
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<tr>
<td>Desai et al.</td>
<td>CO₂ laser for tumour with TORS</td>
<td>2008</td>
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<tr>
<td>Genden et al.</td>
<td>TORS for malignancy</td>
<td>2009</td>
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<tr>
<td>Mukhija et al.</td>
<td>TORS for free flap reconstruction</td>
<td>2009</td>
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<tr>
<td>Iseli et al.</td>
<td>TORS for pharynx and larynx malignancy</td>
<td>2009</td>
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<tr>
<td>Kang et al.</td>
<td>Robotic thyroidectomy using a gasless transaxillary approach</td>
<td>2009</td>
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<tr>
<td>Lee et al.</td>
<td>Robotic thyroidectomy using the bilateral axillary breast approach</td>
<td>2009</td>
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<tr>
<td>Wright et al.</td>
<td>Robot-assisted ansa cervicalis to recurrent laryngeal nerve re-innervation</td>
<td>2009</td>
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<tr>
<td>Kang et al.</td>
<td>Robot-assisted modified radical neck dissection in thyroid cancer</td>
<td>2010</td>
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<tr>
<td>Vicini et al.</td>
<td>TORS for obstructive sleep apnea-hypopnea syndrome</td>
<td>2010</td>
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<tr>
<td>Lee et al.</td>
<td>Robot-assisted submandibular gland resection</td>
<td>2012</td>
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<tr>
<td>Kim et al.</td>
<td>Robot-assisted neck dissection in head and neck squamous cell cancer</td>
<td>2012</td>
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Surgical), which are laparoscopic camera positioning systems, and the Zeus surgical robot (Computer Motion, Goleta, CA). Of these, the da Vinci surgical robot has become the most widely used and has recently received the US Food and Drug Administration (FDA) approval for use in head and neck surgery.

Minimally invasive approaches have been avoided in head and neck surgery owing to concerns about visualization, possible damage to vital structures and the limited availability of effective instrumentation. The limited space available in regions such as the abdominal or pelvic space in the head and neck hinder the use of gas insufflation of the neck, which could induce complications such as pneumothorax. The first surgical use of robots in the head and neck area was in 2005. McLeod and Melder excised a vallecular cyst using the da Vinci surgical robot. In this surgery, only two of the three arms could be positioned in the operative field due to the size of the robot arm; the total operation time was 109 min, with 89 min spent in setup. Since this pioneering surgery, many clinical studies on robotic surgery in the head and neck area have been reported (Table 1).

### Pros

#### Visualization

The operator console provides a threedimensional visualization and high-magnification of the operative field. The depth of the field and the clarity of the tissue planes are enhanced during dissection. These features aid in distinguishing the tissue types in oncological dissection and in reducing unnecessary tissue damage. O’Malley et al. reported that this enhanced visualization allowed them to achieve complete resection with tumour-free margins and excellent haemostasis, while preserving key structures and nerves during TORS for base of tongue neoplasms. Robotic surgery eliminates the ’fulcrum effect’ of endoscopic surgery. Usually, endoscopic surgery requires training concerning the orientation of movement, as the surgeon needs to move his/her hand in the opposite direction to their view. Robotic surgery enables proper hand-eye coordination. Robotic surgery also excludes the need of an assistant to hold the camera. A robot can position an endoscope with better stability than a human, because physical exhaustion is not an issue with a robot, and can enable a better range of motion than conventional endoscopic surgery. Tanna et al. performed two cases of robotic thyroid and thymus surgery in 2006, and they reported improved access and robotic visualization compared with conventional endoscopic surgery.

### Robotic arm and instruments

A robotic arm can reduce physiological tremors that are unavoidable with a human hand by filtering out the hand movement. A surgeon’s relatively large hand movement in the console can be translated into micro-movement in the operation field. This increases a surgeon’s precision. A robotic arm has Endo Wrist instruments having seven degrees of freedom, mimicking human motion: shoulder pitch, arm yaw, shoulder roll, elbow pitch, wrist pitch, wrist yaw and wrist roll. These multi-articulated instruments increase the degree of motion, dexterity and precision. Rahbar et al. opined that the use of the surgical robot on cadaver larynxes was relatively easy for endolaryngeal suturing. Additional surgical instruments can be adapted to the robotic surgery system.
reported that augmentation of TORS with a CO₂ laser can allow easier resection of pharyngo-laryngeal tumours, limiting the thermal effect. Kiaii et al. reported the adaptation of the harmonic scalpel to the ZEUS robotic surgical system and the subsequent safe harvest of the internal thoracic artery. Such refinements have and will continue to enhance the advantages of robotic surgery. Similarly, improved robotic arms and approaches have enabled manipulations that have been previously impossible. A myriad of reports have established the feasibility of robotic surgery. Lewis et al. demonstrated the feasibility of transaxillary robotic-assisted hemithyroidectomy in five cadavers and in a human experiment without gas insufflation. Carol et al. verified that robot-assisted transaxillary thyroidectomy without CO₂ insufflation was feasible with proper instrumentation and an understanding of surgical anatomy. In 2005, Hockstein et al. reported the operative technical feasibility with the three arms of the da Vinci surgical robot through a mouth gag for airway surgery on a mannequin and cadavers. Ray et al. documented the feasibility of robot-assisted selective and comprehensive dissections via combined pre- and post-auricular incisions.

Ergonomics
The design of a robotic console, in which the forearms rest comfortably on a pad and the head rests against the console, is ergonomically desirable and can reduce fatigue and physical stress on the part of the surgeon.

Telesurgery
As described earlier, robotic surgery was originally developed for telesurgery for astronauts or soldiers in battle. Marescaux et al. assessed the feasibility and potential applications of transcontinental robot-assisted remote telesurgery. Suzuki et al. reported a telesurgery experiment using the natural orifice transluminal endoscopic surgery procedure, which was performed at a distance of about 3750 km. These studies clearly indicate the potential of robotic surgery to deliver patient benefits that would be impossible conventionally when the patient and physician are separated geographically.

Training
Robot system could make virtual training a reality. The Vinci Skills Simulator (Intuitive Surgical) can be attached to the console, allowing virtual training. The Temporsurg simulator (VOXEL-MAN Group, Hamburg, Germany and Spiggle & Theis Medizintechnik, Overath, Germany) provides a platform on which patient-specific computed tomography (CT) data can be used for both training and pre-operative surgical planning. David et al. reported a more rapid learning curve reflected by shorter operative times with robotic face lift thyroidectomy compared with robotic axillary thyroidectomy.

Cosmetics
Robotic surgery can yield a cosmetic result that is superior to the conventional approach. The robotic approach allows a smaller incision or an incision in a less visually conspicuous location. Robot-assisted thyroidectomy or neck dissection techniques have been reported mainly from Korea. Reducing scar formation with robot-assisted thyroidectomy in comparison with conventional open thyroidectomy has been reported. Lee et al. described that robot-assisted submandibular gland resection was feasible without significant complications and satisfactory cosmetic results. Kim et al. reported that robotic neck dissection via a transaxillary and retroauricular approach is a feasible and useful method with excellent cosmetic results for treating nodal metastasis in select cases of head and neck squamous cell cancer. The first robotic-modified radical neck dissection of lateral neck node metastasis in papillary thyroid carcinoma was described by Kang et al. They reported that the procedure was technically feasible, safe and produced excellent cosmetic results. Yet, long-term follow-up data concerning survival or recurrence are unavailable.

Operation time
Features of robotic surgery including good visualization and multi-articulated arms can shorten the time for surgery compared with either conventional open surgery or endoscopic surgery. Mukhija et al. reported that TORS reduces the need for mandibulotomy and reduces the time spent in the operation theatre, hospital stay and morbidity. Terris et al. compared robotic and non-robotic endoscopic submandibular excisions and reported shorter operation time using the robotic approach. Tae et al. revealed that robot-assisted thyroidectomy was subjectively easier and took less time to perform a complete total thyroidectomy and central compartment neck dissection than endoscopy-assisted thyroidectomy.

Functional outcome
Robotic surgery results in fewer complications and enables good recovery. Oral cavity, oropharyngeal, hypopharyngeal and laryngeal tumours have been successfully resected with preservation of swallow function. Good functional outcomes reported for TORS include early return to oral intake without enteral supplementation and a low rate of PEG tube retention after adjuvant therapy. The use of TORS for supraglottic laryngectomy decreased the operation time, reduced blood loss and yielded a negative surgical margin in all 13 patients in one study; 11 of these patients were able to resume an oral diet within 24h of surgery with no evidence of immediate airway compromise. Obstructive sleep apnea-hypopnea syndrome has been reportedly managed with TORS, with a decreased apnea-hypopnea index of 17.7 and good functional results concerning pain, swallowing and quality of life. Two uncomplicated cases of robotic-assisted transaxillary

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thyroidectomy with gas insufflation have been described\textsuperscript{43}. Another study reported better postoperative voice function with robotic thyroidectomy using the gasless unilateral axillo-breast approach than with conventional open thyroidectomy\textsuperscript{44}.

**Oncological outcome**

Robotic surgery would not have become popular if the oncological outcomes were worse than those of conventional surgery. Good oncological outcomes of robotic surgery have been established by a variety of reports. Boudreaux et al. documented that low T-stage oropharyngeal tumours and edentulousism seem to favour successful robotic resection and that the use of TORS as a primary surgical method followed by adjuvant treatment offered disease control in both groups of patients with no significant difference in survival\textsuperscript{39}. Chen et al. evidenced improved oncological and functional outcome of TORS\textsuperscript{45}. Moor et al. demonstrated that TORS achieved excellent functional results for patients with oropharyngeal squamous cell carcinoma. Oncological outcomes were equivalent or superior to results of other surgical and non-surgical treatments\textsuperscript{46}.

**Safety**

It has been opined that a robotic arm that does not permit haptic perception could unintentionally hurt or even endanger patients. However, this concern may be relatively minor, based on the findings of a study in which cadavers were intentionally injured during surgery using a da Vinci surgical robot. Only superficial lacerations of the skin and mucosa were produced, with no injury to teeth and mandibles, and no cervical spine fracture\textsuperscript{47}. The aforementioned advantages of robotic surgery, which include enhanced visualization and increased efficiency of the robotic arm, can improve the safety of an operation. The report that robotic micromanipulator control enhances accuracy and repeatability for specific laser tasks\textsuperscript{48} opens the door for alternative user interfaces and additional safety features\textsuperscript{49}. Another study with a canine model provided evidence-based demonstration that effective haemostasis with control of both large and small vessels can be obtained using both surgical haemoclips and electrocautery during TORS\textsuperscript{42}. Majdani et al. found that although the average force generated by the robot during cochlear implant electrode array was slightly greater than the force applied by the surgeon, it was more precise and never reached the maximum force levels generated by the surgeon\textsuperscript{50}. Thus, robotic surgery could limit the maximal power and better ensure safety.

**Cons**

**Cost**

The over-riding disadvantage to robotic surgery is the associated cost. The initial cost of installation of a single unit is approximately US$1.5 million. Annual maintenance will cost approximately US$100,000, and the cost of the disposable instrument is US$200 for a single arm\textsuperscript{46}. These costs limit robot use primarily to large academic medical centres. Infrequent use is another problem. In one report, over 25% of the surveyed institutions in the United States had purchased the da Vinci surgical robot, but 65% of the surveyed departments were not using the system\textsuperscript{51}. Robotic surgery is not yet fully automated. It requires considerable space and additional time and personnel for setup; therefore, it demands additional costs for space, time and labour.

**Visualization**

While visualization can be a pro, it can also be a con. Robotic surgery uses rigid endoscopy such as endoscope-assisted surgery. Flexible endoscopy is not usually used in the robotic surgery. Consequently, exposure is still a problem. Visual obstruction and inter-instrumental collisions can also occur.

**Robotic arm and instrument**

A large robotic arm can preclude the placement of the surgeon’s arm in the operative site. A large robotic arm is not feasible in paediatric surgery\textsuperscript{52}. Besides, it is too heavy to be moved to be adhered to one operation room. Reduction in tactile feel has not yet been overcome\textsuperscript{46}. Loss of haptic perception restricts the information that can be gained in the surgical field, in spite of enhanced visualization\textsuperscript{33}. Robotic surgery could be performed with endoscopic surgery. Miyano et al. demonstrated that total thyroidectomy using bilateral transaxillary endoscopic total thyroidectomy with or without robotic assistance is feasible and safe\textsuperscript{48}.

**Training**

Robotic surgery requires extensive technical training with complex machinery. Training costs can also be considerable. A virtual training simulator has been developed. However, standardized residency curriculums that formally support the teaching of robotic surgical skills do not yet exist\textsuperscript{54}.

**Cosmetics**

While the robotic approach does offer cosmetic superiority, whether this gain justifies the greatly increased cost is debatable. Conventional open surgery with careful wound management does yield good cosmetic results. For example, the results of conventional open thyroid surgery are, in most cases, quite acceptable\textsuperscript{55}.

**Operation time**

The prolonged setup time is a weak point of robotic surgery. The largest controlled case series looking at operative time found that it was increased with the robotic approach, although this may be due to relative inexperience with setup\textsuperscript{56}. In another study, the mean operation time was longer in the robot-assisted group than in the conventional group, but the amount and duration of drainage,
hospital stay, retrieved lymph nodes and complications were comparable.

**Oncological outcome**
No randomized study has yet compared the long-term clinical results of robotic surgery with endoscope-assisted surgery or conventional open surgery. Potential complications of the larger flap associated with robotic surgery have not been studied. A cadaver study reported successful performance of neck dissection from level II to V in all four cadavers, although dissection of levels IIb and Vα, which lie on the cephalic portion of the spinal accessory nerve, was difficult.

**Safety**
Luginbuhl et al. identified the possibility of injury to the brachial plexus during transaxillary robotic thyroidectomy. Benjamin et al. reported that the intraclavicular approach for robotic thyroidectomy is feasible, but it is not safe enough to be recommended.

**Current uses of robotic surgery**
The applications of robotic surgeries are expanding and, for head and neck surgery, are diversifying beyond FDA approval of TORS for T1 and T2 tumours (Table 2). Robotic surgeries are being extensively used for TORS and thyroidectomy, while diverse approaches are being tried for other surgeries including neck dissections and skull base surgeries.

**Overcoming the limitations**
Currently, robotic surgery has many limitations that need to be overcome. The availability of smaller equipment will make a significant impact of the advancement of minimally invasive surgery. A small-size arm could be mounted on the ceiling or the wall of the operation room, increasing access to patient sites. Image integration of the pre-operative image with the surgeon’s view will complete the navigation system, enabling avoidance of vessels and vital structures. Development of instruments such as laser arm and impedance meter to differentiate vessels from nerves is needed. Development of high-speed network will facilitate tele-teaching even from distant countries. Rare diseases could be treated with global healthcare by tele-surgery. Dissemination of robotic surgery and technological development could lower the price of robots. It is anticipated that the aforementioned disadvantages of robotic surgery will be progressively overcome with new approaches and technological developments. Rivera-Serrano et al. reported that the flexible robot technology mitigates laryngeal suspension and the limitation of current robotic surgery with rigid line-of-sight-directed instrument. A new robotic surgical system has been developed that features a compact and modular configuration. The system allows simultaneous installation of four tools and one laparoscope on the abdomen, and it can be attached to the operating table. Johns Hopkins University is currently developing the Snakebot robot that offers greater flexibility and uses a smaller instrument size than currently available. It contains 4-mm snake-like arms that have the potential to contain instruments such as lasers, drills and suction ports.

### Table 2 Characteristic reports of robotic surgery in the head and neck area in 2012

<table>
<thead>
<tr>
<th>Authors</th>
<th>Name of feature of procedures</th>
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<tbody>
<tr>
<td>Balco et al.</td>
<td>Neck dissection through pre- and post-auricular incision</td>
</tr>
<tr>
<td>Byeon et al.</td>
<td>Sistrunk operation, total thyroidectomy, neck dissection</td>
</tr>
<tr>
<td>Mehta et al.</td>
<td>TORS for unknown primary tumours</td>
</tr>
<tr>
<td>Dallan et al.</td>
<td>Transnasal and transcervical dissection of posterior skull base</td>
</tr>
<tr>
<td>Kim et al.</td>
<td>Neck dissection via transaxillary and retroauricular approach</td>
</tr>
<tr>
<td>Koh et al.</td>
<td>Selective neck dissection via face lift approach</td>
</tr>
<tr>
<td>Lallemant et al.</td>
<td>Thyroidectomy with infraclavicular approach</td>
</tr>
<tr>
<td>Lee et al.</td>
<td>Supraomohyoid neck dissection via face lift and retroauricular approach</td>
</tr>
<tr>
<td>Moore et al.</td>
<td>Long-term result of TORS</td>
</tr>
<tr>
<td>Ozer et al.</td>
<td>Supraglottic laryngectomy</td>
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<tr>
<td>Park et al.</td>
<td>Free flap reconstruction after robot neck dissection</td>
</tr>
<tr>
<td>Tae et al.</td>
<td>Robotic thyroidectomy and endoscopic thyroidectomy</td>
</tr>
<tr>
<td>Tae et al.</td>
<td>Voice and swallowing outcome of thyroidectomy</td>
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<tr>
<td>Verzez et al.</td>
<td>TORS with multi-institutional study</td>
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<tr>
<td>Lyer et al.</td>
<td>TORS of T1 and T2 tongue base squamous cell carcinoma</td>
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<tr>
<td>Arshad et al.</td>
<td>TORS of parapharyngeal space tumours</td>
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<tr>
<td>Weinstein et al.</td>
<td>TORS with multicentre study</td>
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<tr>
<td>Weinstein et al.</td>
<td>TORS as a single treatment modality</td>
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<tr>
<td>Kim et al.</td>
<td>TORS for skull base tumour</td>
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<tr>
<td>Van et al.</td>
<td>TORS with YAG laser</td>
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Conclusions
The original computer was far too big and expensive to ever contemplate for personal use. Now, computers and smart phones are ubiquitous and affordable. A similar situation can be expected for robotic surgery. Even within a generation, robotic surgery will become a general option available to many healthcare facilities and budgets. Continued refinements will overcome the present impediments to robotic surgery. Despite this long-term optimism, the present reality of robot-assist surgery including head and neck surgery is not perfect. Moreover, it is likely be that a large number of cases will be dealt with successfully using conventional methods. For young women, in particular, robotic surgery holds appeal over open surgery for thyroidectomy because of avoidance of a scar in the neck area. Whether the cost justifies the cosmetic outcome remains a valid point of debate. For the elderly, in whom a scar is negligible and may not be a personal source of cosmetic concern, using robotic surgery will likely be an option that is hard to justify on the basis of cost. Patients must be well informed of the limitations of robotic surgery, and informed consent can only be obtained after all the other available treatment options have been described. We should always be cautious for developing and adapting a new surgical technique for patients. Sufficient cadaver and preclinical studies should be undertaken before robotic surgery is used for patients. Standardized and formal teaching for robotic surgical skill is necessary. Finally, continued accumulation of evidence regarding technical and oncological safety is vital.

References

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Review


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