Transoral robotic surgery advantages and disadvantages: a narrative review

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Abstract: Robots were used for the first time in surgery back in 1997. Since then abdominal surgeries ensued with robotic surgery 'infiltrating' urology, gynaecology, and thoracic surgery fields as well. Lately, robotic surgery methodologies found application in head and neck surgeries leading to the development of the transoral robotic surgery (TORS). So far TORS has improved work of surgeons dealing with the oropharynx, hypopharynx, larynx, nasopharynx, thyroid, parapharyngeal space and skull areas of the human body. However, with the introduction of such a new efficacious modality, new questions emerge regarding its integration. The purpose of this review is to provide a thorough analysis of the advantages and disadvantages of TORS according to methodologies that have already been applied, along with their economic aspects, surgery processes, benefits compared to conventional surgery techniques, clinical results and any research gaps. Results indicate that TORS technical advantages denote its quality and importance in the field of robotic surgery.

1 Introduction

Transoral robotic surgery (TORS) has emerged as an approach that offers an alternative to open surgery and primary non-surgical treatment, with multiple advantages, such as the ability to operate without line of site restrictions, application of surgical instruments with six degrees of freedom, motion scaling, instrument stabilisation and tremor reduction, as well as binocular and magnified endoscopic vision which allows for accurate three-dimensional (3D) visualisation [1].

As TORS has been shown to achieve excellent oncological results across a number of indications, an overall review of existing applications is hereby attempted in order to concentrate the body of existing TORS-related literature. This paper is more of a narrative review nature, explaining all existing knowledge on TORS and it is based on published research available over the last decade (2007–2017). To achieve that we analysed the existing publications found from online bibliographic databases, finalising the body of our review articles and proceeding with a detailed overview of those articles.

2. State-of-the-art

2.1 Methodology

Search criteria: The review is a narrative review study aiming at identifying the state-of-the-art in the TORS fields regarding economic aspects, the process of surgery, its benefits compared to conventional surgery, the clinical results available so far, as well as any research gaps. A thorough search in electronic databases was conducted using fixed keywords. The search was limited to articles written in English and published since 2007. We decided to examine articles over a 10-year interval, continuing up to the present day. Papers found were screened for relevance (i.e. to confirm that they included the concepts of TORS, leaving a resulting set of papers for full-text appropriateness assessment.

Search methodology: Articles were systematically identified through a combination of computerised database searches and manual searches of the reference lists in those articles. The databases of PubMed, Scopus and ScienceDirect were our main focus. The search was restricted to studies published in conferences and journals, written in English and indexed with the generic following keywords: 'TORS' and 'Transoral Robotic Surgery', as our purpose was to investigate as many applications of TORS in several cases as possible. The search was limited to title and abstract fields, to avoid finding articles, which were not focused on these concepts, yet mentioned the terms.

Exclusion/inclusion criteria: The following criteria were applied for inclusion and exclusion of articles: (i) the literature review concentrates on research published from 2007–2017, (ii) the study excluded research published before 2007 and also excluded non-English language publications, (iii) articles should have been published in journals and conference proceedings, and (iv) articles addressing the use of TORS. Furthermore, we only included articles where their data could be extracted.

Fig. 1 shows the final 88 publications, that our review corpus consists of.

2.2 Analysis

- *Head and neck* [2–22]: This category includes all publications about head and neck carcinomas and tumours and can be divided into four subcategories. The first is about the evaluation [2] and clinical cases [3] of the flex robotic system in TORS, which is a flexible robotic scope that allows the surgeon to access and visualise structures within the oropharynx, hypopharynx, and larynx. The second emphasises on feasibility and technical specs of the Da Vinci System [9–12] and some specific models of it such as the Da Vinci Xi [4–6], S [7, 8] or Si [8] system. The third subcategory includes publications for: clinical studies for head and neck cancer [13, 14, 16], the procedures for the patient selection in TORS [15], studies for postoperative haemorrhage and hospital revisit [18], TORS frontiers [17] and comparative outcomes of concurrent versus staged TORS [19]. The last one includes publications for TORS in paediatric patients with head and neck cancer [21, 22] and more rare tumours such as Ewing's sarcoma of the tongue [20] (see Table 1).
- *Pharynx* [23–30]: This category includes the publications for TORS in pharynx [23–25], nasopharynx (NP) [26] – located to the upper part of the pharynx –, parapharynx space tumours [27, 28] – located deep within the neck and it is a potential space lateral to the upper pharynx – and retropharynx [29, 30] – which is the posterior part of the pharynx – (see Table 2).

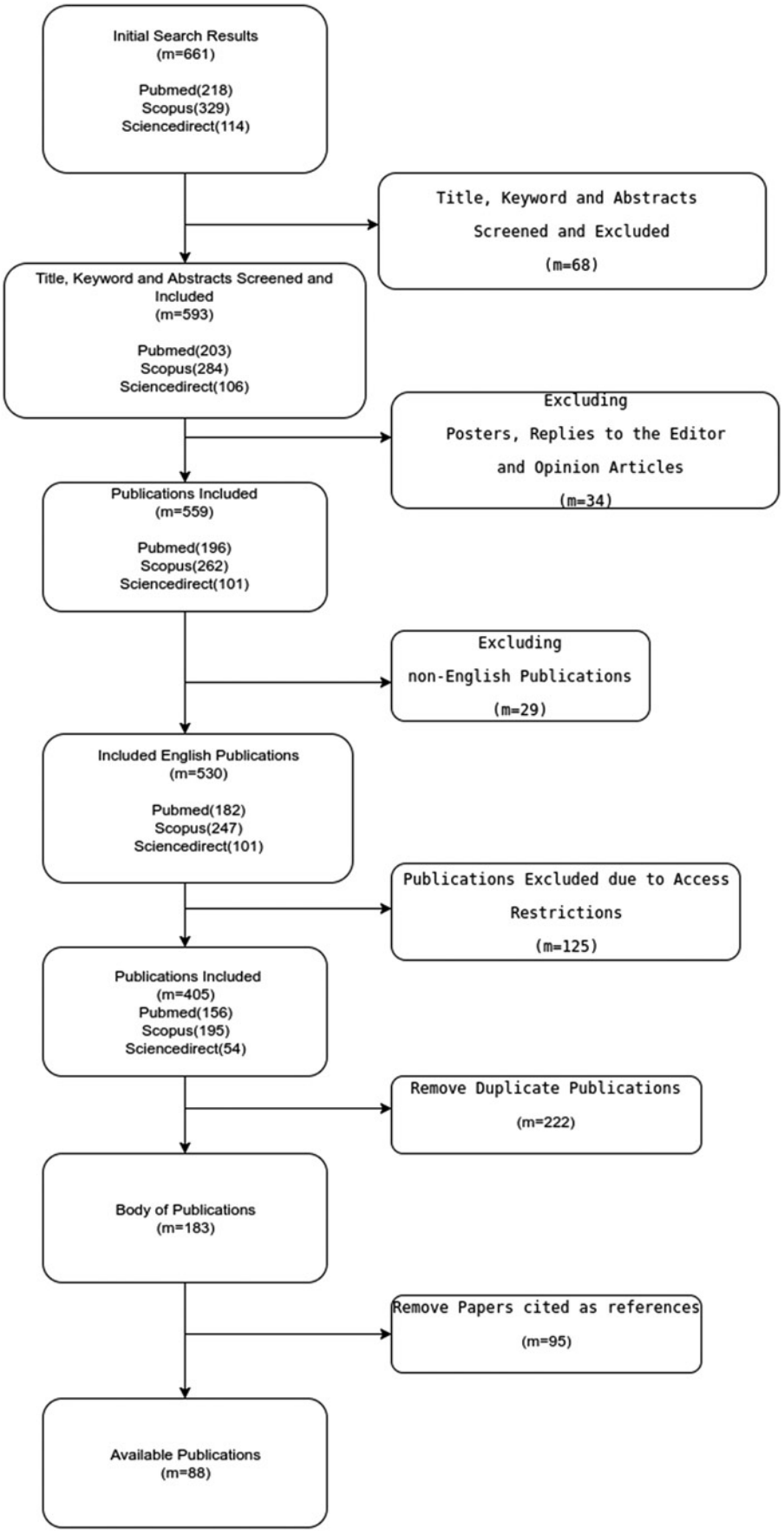

Fig. 1 *Flowchart of the review selection process*

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Table 1 Head and neck TORS findings

Advantages	Disadvantages	Results
[2, 3] 3D-HD (high definition) angled endoscopes in combination with robotic arms improve the visualisation and assessment of anatomic regions that are difficult to envisage. Provides tactile feedback to the surgeon, different cutting devices and two accessory guide tubes The quick system's set up, easily managed by the nurses. [4] Improved and Simplified docking procedure due to four-arm architecture and laser targeting. [6] The digital screen of the driving centre column contains a patient helm. Offering automated guided manual. Offers greater operative reach and range of motion. Cross-patterned laser pointer easily focuses on the target Multi-quadrant access in both the clockwise and the counterclockwise directions. [7] Improved perception and management of the surgical space. Able to use a further assistant hand to maintain a bloodless field. Overcomes Microscopic Limitations. [9] Surgical dexterity. Improved tissue manipulation. Double video endoscope in the patient's mouth. The design of the surgeon's console minimizes the surgeon's fatigue. Improve the functional rehabilitation with less morbidity Decrease the hospital stay. [11] Seven degrees of freedom with precise movement control. Favourable learning curve. Surgical training via on-screen views of anatomy with limited exposure. Ability to draw and take photos/videos on the screen. Improved surgeon ergonomics. [12] Lighting provided by a dual source is better. The surgeon can automatically maintain the position of the instrument Allows greater manoeuvrability in the para median regions. [13] Optics and instrumentation with multiple degrees of rotation. Excellent view of the surgical bed. [14] Decreased morbidities or cosmetic deformities. Improved swallowing and speech functions. [15] Improves locoregional control Minimises the recovery time Reducing toxicity of definitive CRT. Improves the identification the primary tumour.	[2, 3] Requires well-experienced surgeons. [6] Lack of otorhinolaryngologic guidance in the manual. [10] The procedure requires a longer time than the conventional methods Substantial total cost Patients with tumours at an advanced clinical stage or high T-stage were not suitable for TORS. [9] Patients with retrognathia, narrow mandibular arch, and poor neck mobility complicate the TORS. Anatomic characteristics may be exclusion criteria for TORS. [11] The absence of haptic feedback and a bone-cutting arm. Poor transoral exposure, Anterior or posterior commissure involvement, vocal cord fixation, paraglottic space invasion, thyroid or cricoid cartilage invasion, ipsilateral arytenoids cartilage involvement and poor pulmonary reserve can be exclusion criteria for TORS. Airway fire/oedema/obstruction. Poor exposure leading to procedure abandonment. Tongue numbness. Hoarseness. Need for a G-Tube (gastrostomy tube) and laryngeal stricture. Prolonged swallowing dysfunction. [14] Patients treated with TORS, without flap reconstruction may have fewer stem cells in the primary surgical bed. Fewer stem cells may remain in patients with larger tumour and greater depth of invasion. Unexpected delays in wound healing and soft tissue necrosis. [16] Possibility of lip, dental or mucosal injuries. Facial lacerations Cervical spine or ocular injury. Mandible fracture. [21, 22] Patients are small in size, there is an inherent higher risk of introducing and manipulating robotic instruments and scopes transorally compared to adult patients. Patients are small in size, there is inherent risk in using robotic instruments and scopes transorally.	[2, 3] Lesions, even in difficult accessible areas, such as BOT, were successfully resected, and as a result, the system seems to be a safe and effective tool in TORS. [4] Satisfactory Feasibility to perform TORS. [5] Seated TORS of the BOT, inferior pharynx, and larynx was safe and feasible. [6] Improved anatomic access, with better-equipped appurtenances. [7] A suitable tool for upper aerodigestive malignancies treatment. [8] TORS can have an additional role in the treatment of difficult to treat salvage patients group. [10] Primary tumours can be completely resected en bloc, reserving as much swallowing and speech as possible. TORS is emerging as a standard of surgical care in cancers of the head and neck where it is indicated. [9] TORS preserve oncologic control on surgical resection margins for resection of head and neck cancers of various stages and localisations. [11] TORS partial laryngectomy leaves raw mucosal surfaces to heal, where the blood supply after RT, is tenuous and leads to prolonged wound healing. Desired outcomes of TORS laryngeal and hypopharyngeal cancer surgery include cancer extirpation with negative margins and maximisation of functional and QOL outcomes. Need for a temporary G-Tube is uncommon Patients with larger tumours and those undergoing simultaneous neck dissection are slower to recover swallowing function. [13] En bloc tumours removal via minimally invasive surgery without a cervical incision, while preserving function and potentially avoiding adjuvant radiation and its long-term sequelae. [14] Adjuvant RT or concurrent CRT after TORS is recommended to improve local control and overall survival. [15] Allows excellent functional outcomes after resection of head and neck tumours that previously required morbid surgical approaches for access. A valuable method of de-intensification for the locoregionally advanced patient. [17] Through TORS, surgeons have been able to visualise areas and successfully inset free flaps in a minimally invasive manner. [18]

Continued

TABLE 1 *Continued*

Advantages	Disadvantages	Results
Decreasing the dose of RT Obviating the need for chemotherapy. Decreasing the RT target volume. [16] Lower risk of blood transfusion. Less pain. Decreased blood loss. Avoiding tongue necrosis. Lower risk of tracheostomy placement Decreased need for a nasogastric or gastric feeding tube. Scars and incisions avoidance. Avoiding malocclusion or malunion of the jaw. [17] Resect lesions of the upper aerodigestive tract without entering the neck. [20] TORS offers a wider variety of technical options for haemostasis.		Postoperative dysphagia was the single most common indication for hospitalisation or intervention after TORS. Haemorrhage rate after TORS was low. [19] Patients have similar postoperative outcomes with respect to inpatient complications, readmissions, and the need for additional procedures that affect QOL. [20] Haemostasis was easily managed in the live surgeries with either monopolar or bipolar cautery robotic instrumentation and the use of small-sized haemoclips. TORS offers a complete excision of a tumour and therefore the best outcome. [21] Applying TORS to the paediatric population can be feasible and safe for appropriate airway pathologies.

Table 2 Pharynx TORS findings

Advantages	Disadvantages	Results
[23–25] Smaller approach than the external one. Inverted palatal view. Allows having both the hands of the surgeons working and hands of the assistant afforded by the robotic system. [26] Use of three instruments to perform transoral endoscopic nasopharyngectomy provides traction and counter-traction in the confined space of the NP. Digital zoom and motion scaling. [27, 28] Tremor filtration, angle dinstrumentation and increased freedom of instrument movement. More delicate handling of tissues, hence healthy tissue preservation. Precise resection with clear surgical margins. Avoid external incisions and scars.	[26] Instruments size is larger than ideal for use in the head, neck, mouth and especially into NP, which is an even smaller space urther confined by bony walls. There are no instruments capable of dividing or removing bone, which often tumours of the NP involve. [27, 28] Limited cervical spine mobility. Requires significant experience and training. [29] Poor exposure and visualisation to RPLNs.	[23–25] No change in preoperative and postoperative swallowing functions. No patient newly required gastrointestinal tube postoperatively. The high completion rate in comparison with other transoral surgical procedures. Low recurrence rate with branchial cleft fistulas managed without tonsillectomy [26] TORS can be adapted to perform robotic nasopharyngectomy without the need to completely divide the soft palate. [27, 28] Safely excising selected parapharyngeal spaces masses with minimal morbidity to the patient. Approaching the skull base is difficult to dissect with TORS alone and might require a transcervical assist for removal. [29] TORS for RPLNs increases the risk of severe short-term dysphagia and dysphagia-related complications.

• *Oropharynx* [1, 31–52]*:* This category includes all the publications related to TORS, which refer to oropharyngeal carcinomas and tumours. The first subcategory includes publications which present the outcomes following TORS for oropharynx squamous cell carcinoma (OPSCC), such as swallowing, speech and quality of life (QOL) [40], the oncologic and functional outcomes [39, 52], postoperative bleeding with and without external carotid artery ligation [44]. Also, there are publications which compare the oncologic and functions between TORS and a treatment-surgical approach [46], such as TORS versus definitive chemo-radiotherapy (CRT) [41] and TORS versus traditional open surgical approaches [43]. The second subcategory includes publications which present a modified TORS approach, such as using magnifying endoscopy with narrow band imaging (ME-NBI) with TORS in order to provide high-resolution images and to detect early superficial pharyngeal cancers [34], or using a miniaturised high-resolution fiberoptic microendoscope with TORS for providing real-time histological assessment [36]. Also, another publication proposes a modified TORS approach in which transoral mandibular osteotomies are performed that can greatly improve exposure to oropharyngeal subsites and expand access to the larynx in selected patients [37]. The third subcategory

Table 3 Oropharynx TORS findings

Advantages	Disadvantages	Results
[31] Shorter hospital stays. Lower rates and duration of tracheostomy and gastrostomy use. Fewer respiratory, bleeding and wound complications. [1] Allows resection of tumors which traditionally would require a pharyngotomy or mandibulotomy. [34] Combination of TORS with ME-NBI. Early diagnosis. Less invasive treatment. Beneficial in avoiding excessive resection, due to easily identification of the boundary of the superficial lesion. [36] Prediction of histology is enabled using microendoscopic imaging. Real-time visualisation of the epithelium at a subcellular level of resolution. [37] Transoral mandibular osteotomies improve surgical access without the increased morbidity of transmandibular or transfacial approaches, which would be required in many patients with inadequate access for TORS. This technique can be applied to any transoral surgery (TOS) requiring increased access. [39] Patients had significantly better eating ability and dietary intake after 2 weeks of treatment, compared to patients treated with chemoradiation. Surgical patients experienced a return of their oral dietary intake after 1 year, whereas patients treated with chemoradiation continued to have decreased oral diet. [41] Patients treated with TORS had better short-term eating scores and improved long-term dietary intake. [43] Patients who underwent TORS were shown to have significantly improved outcomes in speech and swallowing functions, compared to those who underwent open surgery. [45] Functional outcomes for T1-T2 patients have been promising with low G-Tube dependence at 6 and 12 months. Improved dysphagia scores at 1 year. [46] The histopathological information gained improves staging and guides subsequent decision making, providing useful information for tailoring therapy, or personalising treatment commensurable with the disease. [49] Complete recovery of swallowing was reported in patients treated by TORS in 6 days, including rapid functional decannulation and shorter hospital stays, whereas patients undergoing conventional surgery did not show complete recovery of swallowing even until 12 days. Reduced blood loss (<200 ml).	[31] One patient with a long history of NP carcinoma treated with RT and recent oropharyngeal carcinoma treated with TORS presented post-operatively with a progressive. exophytic and invasive candidiasis of multiple non-albicans species mimicking recurrence of oropharyngeal cancer. [1] TORS related complications: Bleeding. Dysphagia. Local oropharynx. Pneumonia/aspiration. Local pain. [33] A large percentage of patients will still receive adjuvant CRT or RT on top of surgery. [34] Limitation of ME-NBI is that ME-NBI is not useful for examining deeper tissue beneath the epithelium. [36] Limitation of this technology is that it is restricted to the superficial mucosa. Imaging of the deep muscle margins with this technology remains unexplored. [37] While the functional impact of the addition of a mandibular osteotomy during TORS surgery remains unknown, the procedure does increase the possibility of additional morbidity and increases operative time. [49] The high initial purchase cost of the robotic system (approximately 1.5–2.0 million dollars). Increased expense of instruments (about one thousand dollars per case). High maintenance cost (~1 million dollars/year). Large equipment size and weight demanding more physical space requirement. Lack of sensory tactile sensation and demand for hand eye coordination with the significant learning curve. Limited accessibility and bulky instruments. Minor complications like transoral bleeding, exacerbation of sleep apnoea from postoperative swelling, moderate trismus, and temporary hyper-nasality of voice. Other limitations that can particularly limit its use in oral and maxillofacial surgery are lack of haptic feedback and inability to cut or drill bone.	[31] For future patients, it is appropriate to have fungal culture and be treated according to the results of the culture. There is a definite need to consider tumour recurrence, despite initial biopsy showing granulation tissues with no neoplasia. [1] Age over 60 years and a larger extent of resection were the significant factors predictive of major complications. [32] Introduction of a TORS program in an academic medical centre can be a complex and daunting undertaking. However, with careful planning, excellent outcomes can be achieved while reaching maximal efficiency upon program initiation. [33] Ability to reduce the requirement for postoperative RT/CRT and maintain excellent functional and oncologic outcome for primary and secondary oropharyngeal cancers treated with TORS. [34] ME-NBI with TORS will make it possible to achieve a higher ratio of minimally invasive treatment in pharyngeal cancer. [36] A microendoscopy device can be safely and successfully used to acquire high-quality, high-resolution images of cellular morphology and architecture in the real time of the oropharynx during TORS surgery. This technique may serve as a valuable adjunct to ablative oncologic surgery, potentially improving tumoral margin discrimination and oncologic outcomes. [37] Mandibular osteotomy should be considered for patients who would otherwise be candidates for TORS but have limited access. This approach has the potential to broaden the application of TORS for patients, regardless of body type and treatment-related morbidity. [40] Patients who undergo external beam radiation tend to demonstrate worse health related QOL scores, but by 12 months post TORS, overall QOL returns to baseline values. G-Tube rates are low. However, patients with older age, more extensive resections, and advanced pT classification are at increased risk of needing or retaining a G-Tube. These results suggest that TORS is a viable alternative to primary CRT in OPSCC treatment. [41] The treatment, complications of treatment, and recurrences during the illness trajectory of oropharyngeal cancer are all associated with disutility. Treatment with TORS, however, may serve to minimise this disutility. TORS showed better utility scores using standard gamble than definitive RT and CRT and was preferred in paired comparisons.

Continued

TABLE 3 *Continued*

Advantages	Disadvantages	Results
Decreased postoperative pain with lesser dependence on tracheotomy or G-Tube. Minimal scarring. Reduced risk of infection from the wound. Rapid recovery times. TORS include the ability to stage a tumour adequately and eradicate a primary tumour along with involved lymph nodes reliably and completely in a single setting. ME-NBI is an innovative optical technology that increases the contrast between precise morphological changes in mucosal surface and normal tissue thus helps in estimating the precise extent of a tumour. [50] Medrobotics Flex System is particularly designed to provide visualisation and access for surgical procedures, which require a non-linear advancement of surgical instruments, such as in TOS.		[42] Implementation of an alternative to the traditional RT regime demonstrating that TORS and concurrent neck dissection is a safe and feasible procedure for patients with early stage OPSCC. [45] TORS compares favourably to traditional open surgical techniques for OPSCC that are morbid. Contemporary non-surgical therapies have relatively poor locoregional control and survival in HPV negative OPSCC. [46] Minimal, temporary effects and fewer detrimental effects on QOL substantiate that TORS reduces the overall morbidity associated with current classis CRT treatment. [47] TORS is not yet ready for a recommendation for all patients with advanced oropharyngeal carcinoma, due to limitations which exclude many patients. [48] TORS with radial forearm free flap reconstruction is a safe, effective and potentially cost-saving alternative to the lip-splitting mandibulotomy approach for the treatment of advanced stage OPSCC. [51] Technological advances with conformal radiation and TOS especially with TORS have facilitated the potential to reduce long-term swallowing complications and may possibly improve oncologic outcomes for resectable OPCSS. [52] In this study, pooled data of early results suggest good disease control rates and good functional outcomes with low surgical morbidity and mortality when using TORS for the early stage OPSCC.

Table 4 Hypopharynx TORS findings

Advantages	Disadvantages	Results
[53] No tracheostomy or G-Tube placement was required. Blood loss was minimal. [56] Allows for wristed instruments and tremor-reduction technology to provide surgeons with improved control of limited surgical fields.	[53] Patients with an insufficient transoral view and/or involvement of thyroid cartilage or prevertebral fascia not eligible. [55] A single incision made by unipolar cautery is wider and deeper compared with a laser, and more thermal damage to the surrounding tissue occurs as well. Some patients required additional margin resection because of the frozen section preliminary report showing dysplasia on margins after the neck dissections.	[55] TORS without the tracheostomy procedure can be successfully executed with en bloc resection of the early pyriform sinus tumour. Use of a carefully detailed margin assurance probably helped to achieve good local control. The hospitalisation duration is shorter for TOS. Soft oral diet was initiated after 24 h of surgery. During follow-up, a minority of patients required temporary tracheostomy and parenteral G-Tube insertion because of partial airway obstruction and dysphagia or needed parenteral G-Tube transiently during RT.

included publications which present application of TORS for OPSCC [33, 51], such as a study from a Danish head and neck cancer centre that aims to demonstrate the feasibility of performing primary TORS and concurrent neck dissection [42], a review of utility of TORS for HPV negative OPSCC [45], a critical literature review on TORS, a presentation of a case in which successful visualisation and resection of an OPSCC is demonstrated using the novel Medrobotics® Flex®System [50], and a case of invasive

Table 5 Larynx TORS findings

Advantages	Disadvantages	Results
[58] There are many tricks and solutions that increase the ability of adequately exposing and managing the area of interest. [59] Very adaptable and precise. Easy to control bleeding during the operation. Avoidance of excessive removal of normal tissues. [60] Wider field of view. Vascular control and haemostasis can be obtained. Improved ability to dissect the external portion of the laryngocele. Reduced morbidity. [61] Good haemostatic function in anterior commissure resection. Minimal the perioperative morbidity Able to perform without tracheostomy. [62] Improvement of margin assessment. [63] Access to deep sites in a minimally invasive fashion. Exemplary instrumentation for the precise and delicate handling of tissue. Reduces involvement of surrounding structures and healthy tissues. Preservation of organ structure and function. [64] Technical improvements. Improved observing experience for students and surgeons-in-training. [65] Significantly reduced blood loss.	[57] Patients' selection is critical. Need for experienced surgeons. Skin necrosis from transoral dissection of the subcutaneous tissues. Dental injury. Device malfunction. Bleeding. Airway compromise. [58] Surgical space must be large enough to handle the anatomic structures. Conflict with the access window. Reduced interincisive distance. The short and stiff neck can be a limiting factor. [61] Patients with trismus, long teeth, a big tongue, or retrognathia are not good for TORS. [62] Tactile feedback in endoscopic operation is limited or not possible. [63] Inadequate access to tumours can cause unsuccessful completion of TORS. Patients with small mouth opening, prominent dentition, limited neck flexion, micrognathia, bulky tumours, and irradiated tissues are not able for TORS. The difficulty of endolaryngeal suturing after the removal of the specimen. [64] Requires an advanced understanding of endolaryngeal anatomy and experience. Requires optimal transoral exposure.	[57] Use of TORS for salvage surgery may lead to delayed healing and worse functional outcomes. TORS of the larynx is an effective and safe method to manage laryngeal cancer in the primary and salvage setting. Swallowing and airway function are excellent in most patients. [58] In difficult cases of laryngeal exposure, TORS proved to be a possible salvage option. [59] Appropriate treatment for small or medium-sized laryngeal haemangiomas. [60] TORS approaches are effective in management of combine laryngoceles. Limitations of the approach do not appear to be related to the size of the laryngocele. [61] Acceptable results of average mild dysphonia. Negative final frozen section margins. No risk of long-term irradiation complications. [63] TORS total laryngectomy is a more daunting endeavour. Both supraglottic and total laryngectomy were performed successfully in the cadaveric model. Surgical access to the larynx using the flex robotic system has great potential for management of laryngeal malignancies. [64] Total laryngectomy and glottic cordectomy have been adapted through TORS with encouraging initial results. The robotic approach has even been proposed as an alternative for patients who otherwise cannot be accessed through standard microlaryngoscopic exposure. Oncologic outcomes following TORS supraglottic laryngectomy continue to demonstrate excellent disease control and excellent overall survival. TORS supraglottic laryngectomy can be offered with the infrequent need for upfront tracheostomy or gastrostomy and can expect about a 4-day hospital stay. Improvement of TORS approach targets the formation of the pharyngocutaneous fistula with a limited pharyngotomy defect reducing the length of mucosa at risk for breakdown. [65] Limited postoperative pain as well as swallowing and psychosocial distress. TORS was not associated with higher locoregional recurrence rate compared to other methods.

candidiasis in an immunocompetent patient with previous radiation therapy (RT) years ago who underwent TORS [31]. The fourth subcategory includes publications which compare TORS with other surgical approaches [47, 48]. The final subcategory includes the publications which refer to education in TORS, such as the review of an implementation of TORS in a busy academic centre [32], how to assess learning curves for the oncologic TORS surgeon and to identify the number of cases needed to identify the learning phase [35], and a development of a robotic surgery training regimen integrating objective skill assessment for otolaryngology and head and neck surgery trainees [38]. Finally, one publication presents the complications which may occur following TORS and how to identify the factors predictive of complications [1] (see Table 3).

- *Hypopharynx* [53–56]*:* This category includes the publications for TORS in hypopharynx [53–56]. Patients with hypopharyngeal carcinoma have the worst prognosis among all patients with head and neck cancer. The survival rate of patients with hypopharyngeal

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Table 6 Thyroid TORS findings

Advantages	Disadvantages	Results
[68] The absence of a visible scar. Relatively minimal dissection. The advantage in the restricted workspace. Better dissection in smaller spaces without arm interference. Better operative times. Better exposure. Ease of dissection to the thyroidectomy. Limited tissue dissection and retraction. Close access to the thyroid gland. Natural orifice surgery. No cutaneous scar or deformity. [70] Enhances the ability of the surgeon to manage this complex region.	[66] Limited mouth opening influencing exposition and manipulation. Restriction in oropharynx exposition. [67] Bleeding in some cases. [68] Lack of tactile feedback. Difficulty with exposure. Robotic arm collisions when operating in a narrow working field. Not every patient is eligible for TORS.	[67] Decreases morbidity and duration of the operation. No significant difference between transoral laser microsurgery (TLM) and TORS. [70] Postoperative discomfort has been proven to be very low.

Table 7 Tongue TORS findings

Advantages	Disadvantages	Results
[72] Use of the robotic arm for positioning and moving the scope within the operating field constitutes another beneficial aspect of this technique. 5 mm instruments moving in all the spatial planes allow the surgeons better manipulation of the tissues. Monopolar cautery allows the removal of higher amounts of tissue with less postoperative morbidity (e.g. oedema, nerve injuries) in comparison with the CO_2. The ability to work with five 'hands' (three robotic arms and two instruments).	[72] Pesection of the BOT with TORS is clearly expensive and should be reserved for the management of disorders with high cost-effectiveness ratio as well as after other treatments.	[72] No evident blood loss was reported during the procedure and no serious postoperative complications. Lingual tonsil resection by means of the robotic technique seems to be feasible and well tolerated in patients affected by lingual tonsillitis. Effective and stable results. The procedure is safe, easy to learn and not associated with the major complication.

Table 8 OSA TORS findings

Advantages	Disadvantages	Results
[77] Improved surgical access to the BOT. Easier access to the BOT and offers. Comparable efficacy to open procedures with less morbidity. [78] Reduction in the apnoea-hypopnea index. Increase in the lowest oxygen saturation. Reduction in Epworth Sleepiness Score. Visual analogue scale reduction.	[78] Taste alteration. Tongue numbness. Tongue soreness. Bleeding. Oedema. Dysphagia. Few patients with significant intraoperative, haemorrhage postoperative, bleeding requiring additional surgical intervention, and an instance of postoperative oropharyngeal stenosis requiring a Z-plasty. [79] Anatomy of the patient must also be amendable to access with the robot. Precise localisation of the hypoglossal nerve, lingual artery, and lingual neural branches is not possible.	[76] No significant short-term impacts or aspiration. Rapid start of oral feeding with no need at all for the nasogastric tube. Short the hospital stay and hast the patient discharge.

cancer has not been significantly improved, although different treatment modalities have been developed [53] (see Table 4).

- *Larynx* [57–65]*:* This category includes publications for partial and total laryngectomy [57, 58], glottic laryngectomy [61], supraglottic laryngectomy [62–65] – one of the most common applications of robotic-assisted surgery for laryngeal cancer –, combined laryngocele [60] and haemangioma of the adult larynx [59] (see Table 5).
- *Thyroid* [66–70]: This category includes the publications for TORS in the pharynx, which focus on the clinical findings, surgical management, and outcomes for lingual thyroidectomy [66–70]. The ectopic thyroid gland may be detected at any place between the foramen caecum and normal thyroid localisation due to the inadequacy of the embryological migration of the thyroid gland [66] (see Table 6).

Table 9 CUP TORS findings

Advantages	Disadvantages	Results
[81] Augmented visualisation during TORS offers a potential technologic advantage in addressing CUP. [83] TORS BOT mucosectomy has the potential to alleviate diagnostic uncertainty. Also, provides an adjunct treatment modality with low complication rates.		[81] This novel surgical approach improves identification rates of occult mucosal malignancies compared to traditional endoscopic and radiographic approaches. Also, this approach has reduced the need for chemotherapy as well as radiation in select patients who would otherwise be treated with comprehensive CRT to all at-risk mucosal sites. [82] This study demonstrated an initial gradual decline in all domains during the completion of the entire treatment regimen when compared to baseline scores. The lowest scores were detected at 3 months, followed by progressive improvement towards the end of 1 year. All QOL scores returned to preoperative levels at 12 months except eating scores, which were significantly low. [83] Evaluation of the role of TORS BOT mucosectomy in head and neck CUP as a diagnostic tool, as a treatment adjunct and as a tolerable, low-risk procedure. Our cohort size was small but provides sound support across all three domains.

Table 10 General TORS findings

Advantages	Disadvantages	Results
[84] Excellent visual access. Safe grasping and dissection and the ability to use an assistant to introduce further surgical tools. The ability to anipulate the tissue during resection and to suture the tissue during reconstruction. TORS eliminates the development of granulation tissue and provides control over healing. [85, 86] Minimally invasive.	[85] Not all patients are eligible for TORS. Da Vinci surgical system, the most common robotic system for TORS so far, has been designed for general surgery making the size of robotic arms quite big for transoral operation. [86, 87] Lack of 'natural' tactile feedback. The high cost of the robotic equipment.	[87] No infections or other complications related to prolonged surgical duration. [88] Limited surgical morbidity, mortality, shorter hospital stay, good haemostasis, less pain, and postoperative maintenance of QOL.

- *Tongue* [71–75]*:* This category includes the publications for TORS in tongue, which focus on the tongue-base adenoid cystic carcinoma resection [71–75]. Adenoid cystic carcinoma is a salivary gland tumour, with a much lower occurrence rate on the tongue base, which is a relatively uncommon malignancy, whose etiology remains unclear (see Table 7).
- *Sleep apnoea* [76–80]*:* This category includes the publications for patients who underwent TORS for sleep apnoea [76–80] on both short- and long-term scales to evaluate the clinical efficacy of TORS of the tongue base reduction on sleep-related outcomes in patients with obstructive sleep (OSA) (see Table 8).
- *Carcinomas of unknown primary (CUP)* [81–83]*:* This category includes the publications which are related to carcinomas of unknown primary. The first publication presents the role TORS in facilitating the identification of a primary tumour site for patients presenting with squamous cell CUP (UPSCC) [81]. The second publication presents the functional outcomes, such as speech, eating, aesthetics, social disruption, and overall QOL over a year for patients who underwent TORS [82]. Finally, the third publication presents efficacy, diagnostic rates and complications associated with TORS base of tongue (BOT) mucosectomy over a 7-year chart [83] (see Table 9).

2.3 Concentrated tables of results

See Tables 1–10.

3 Conclusion

According to Tables 1–10, TORS represents an innovative endoscopic therapeutic alternative in the fields of head and neck treatment regarding tumours, with many advantages compared to endoscopic surgery. The computerised mechanisation of TORS allows deeper and easier access, as well as dissection of anatomical sites, due to the increased range of motion of the surgical arms. It is also proven that it scales the movements of surgeons, as large hand movements are translated into micromovements. Thus, it improves precision and allows complete resection of tumours, while preserving key structures and nerves. Furthermore, it offers a robotic 3D view and provides lighting by a dual source, which is more efficient and robot terminals can be inserted near the surgical field. An anti-tremor filtering and the automatically maintenance of the position of the instruments improves the outcomes of the surgery. Moreover, due to several surveys, TORS is associated with less pain, faster recovery, decreased the time of hospital staying and shorter operative times. It seems to be a safe, feasible and effective alternative to open surgical or standard nonsurgical treatment in patients and promotes a decrease in morbidity and achievement of a better functional and cosmetic outcome.

Like any other technique, even TORS is fraught with certain drawbacks and concerns such as conflicts between robotic arms during surgery, sometimes requiring several repositionings, which depends on the patient's anatomy and the tumour site. Skull base TORS cannot be a fully robotised technique at the moment and another concern is the lack of haptic feedback, which should be improved by technological developments. One more disadvantage of TORS is its high initial purchase cost and the large size of equipment and robot-specific supplies, while a few patients are unable to undergo transoral procedures due to anatomic limitations.

So far, TORS applies in the cases of head and neck, pharynx, oropharynx, hypopharynx, larynx, thyroid, tongue, sleep apnoea,

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carcinomas of unknown primary. Through TORS, surgeons have been able to visualise areas and successfully inset free flaps in a minimally invasive manner [17]. Although there were complications through the above applications such as a few cases of mild dysphonia, negative final frozen section margins [61] and increased risk of severe short-term dysphagia and dysphagia-related complications in retrophangeal lymph nodes (RPLNs) cases [29], high completion rate in comparison with other transoral surgical procedures was achieved [23–25], reserving as much swallowing and speech as possible [10, 57] and there was no need for gastrointestinal tube postoperatively [23–25].

4 Limitations and recommendations

The aspects of TORS discussed in the previous sections are sufficient, but they may face some limitations. We were unable to translate publications written in languages other than English so valuable information may have been missed. This review contains publications from January 2007 until June 2017, so publications exceeding this period are not included. Also, publications which were not available for free on the web are not included.

As the nature of this review is narrative, results regarding clinical and technical aspects of TORS might not have been presented in detail. This first overview of TORS applications aims to serve as a helping guide for any interested stakeholders to identify and map advantages and disadvantages of this newly applied technique of robotic surgery.

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