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Transoral robotic surgery in maxillofacial surgery: Systematic review of literature on current situation and future perspectives

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Introduction

Transoral robotic surgery (TORS) is defined as the robotically-assisted surgery performed through the oral cavity.[1] One of the first applications of TORS in benign pathology was described in 2005 by McLeod et al in a patient for the excision of a vallecular cyst,[2] while one of the first treatment of malignancies was realized by O'Malley in 2006 on a canine model for a glottic tumor.[3] Currently, the most employed robot is the Da Vinci Surgical System that consists of three components: a surgeon's console, a patient-side robotic cart with four arms, and a high-definition 3-dimensional vision cart. The robotic instruments are easily introduced trans orally and allow the surgeon to perform procedures equivalent to open surgery, with the advantages of reduction of hand tremors and fatigue, enhanced three-dimensional High-Definition visualization, decrease of blood loss and postoperative pain, reduced risk of wound infection and aberrant scars.[4]

In the recent years TORS has been extensively used for the treatment of otorhinolaryngological pathologies, in particular benign and malignant diseases of the soft tissues of palate, palatine

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tonsils, base of tongue and oropharynx, posterior and lateral pharyngeal wall, parapharyngeal space, larynx, hypopharynx even to thyroid. Several Authors have already shown TORS effectiveness and validity in terms of no residual lesions, negative surgical margins, no recurrence in the treatment of pathologies of these districts, with the advantage of avoiding mandibulotomy.[5-9] However, in oral and maxillofacial surgery and in particular in the management of hard tissues pathologies, the use of TORS is still under study and its applications are in continuous development, through scientific searches both on patients and on animals/phantoms.

The aim of our study was to perform a systematic review of the literature to investigate the role of TORS in the treatment of pathologies, in adult population, related to oral and maxillofacial surgery, to evaluate the current situation and the future perspectives. Interesting articles about studies on animals or models to investigate the role of TORS on hard tissues, although excluded from the review, will still be analyzed to describe the future direction of this surgical approach.

Materials and Methods

Study protocol

The review was performed according to the protocol of the Preferred Reporting Item for Systematic Reviews and Meta-analyses (PRISMA) statement.[10] The review protocol was designed a priori, defining methods for collecting, extracting and analyzing the data. Three authors (LR, PB, SS) independently evaluated data from eligible studies, which were then checked by a fourth author (VA).

Search Strategy and Eligibility Criteria

The literature research was conducted using different databases: PubMed, Web of Sciences, MEDLINE, Embase, Scopus, Google Scholar and Cochrane Library. The search was performed using the combination of the following keywords: “transoral robotic surgery” OR “TORS” AND “maxillofacial surgery” OR “face” OR “orofacial”. Given the small number of articles, derived using these keywords, also a search using the mesh terms “transoral robotic surgery” AND “Head and Neck” was performed and then the relevant articles were manually screened. The research covered the literature up to 18 August 2023. Duplicates were selected and then removed using Endnote online software (Clarivate Analytics). Only the papers in English language were included in the study; similarly, only the studies on humans, in particular in adult population, and the articles with an abstract were considered for the review. The conference abstracts were not considered in the review; an additional research through the bibliography of the eligible articles was also performed trying to avoid an incomplete literature analysis. The records assessed for the eligibility were fully read and screened following these inclusion criteria: in the present systematic review, all the studies that involved the oral and maxillofacial district were included; also the paper considering the parapharyngeal and styloid space were included. The papers involving oropharyngeal, hypopharyngeal and laryngeal space and thyroid were excluded, giving the prevalent otolaryngological pertinence. The papers had to contain information about a surgical procedure performed with TORS, reporting the outcomes, the complications and type of used robot. The articles whose title did not specify TORS procedure were excluded from the review as well as the papers involving another type of robotic-assisted procedure.

Data extraction

Data extracted from the included studies were about: the type of study, the country, the number of analyzed cases, the field of application of TORS, the type of used robot, the treated disease, the operative time of surgery, the obtained outcomes and the complications that occurred. In particular, the review analyzed the type of intervention and the success rate: for tumors, the success of procedure was considered as the absence of residues or recurrences after excision or as the detection in unknown primary case; for surgery of correction of OSAS (Obstructive Sleep Apnea Syndrome) the success was considered as the reduction of pre-operative AHI (Apnea-hypopnea index) $\geq$ 50% or AHI $<$ 20; for Eagle's Syndrome treatment the success was considered as the improvement of symptomatology. Regarding the complications, the rate was calculated as the average percentage of the various studies.

Results

Studies Selection

A total of 468 articles were initially identified from the different Databases; of these, 302 duplicated studies were removed and 4 studies were excluded because not in English language. At the remaining 132 papers, other 9 papers from bibliography were added for the screening, for a total of 141 articles. Thus, 70 papers with no pertinent title were excluded; and papers without abstracts (n=5) and studies no on humans (cadavers, animals or phantoms) (n=6) were removed. Thus, 60 articles were assessed for eligibility and scrutinized: after the exclusion of studies not satisfying the selection criteria, 38 studies were included in the systematic review[11-48] and resumed in Table 1. The PRISMA flow-diagram is illustrated in Figure 1. Six interesting papers[49-54] about maxillofacial diseases but not satisfying the inclusion criteria, were excluded from the systematic review but equally analyzed in Table 2.

Studies Characteristics

The general features of the included studies are shown in Table 1. Thirteen studies were performed in Italy (34.3%), nine in the USA (23.7%), three in Australia (7.9%), two in Taiwan, China and United Kindom (5.3% for each one) and one in Nepal, Poland, Israel, India, Denmark, France, South Korea (2.6% for each one). The design of most studies was observational (34.3%); the remaining articles were case report (23.7%), systematic review (15.6%), narrative reviews (13.1%), case series (7.9%) and technical note (5.3%). Not considering the reviews, all the studies were performed in a single center.

Data Analysis of the selected studies

All the considered patients were 3630, with 13.9% of women and 86.1% of men, with a median age of 47.7 years.

Aim of TORS procedures

TORS was employed in these different surgical procedures: in 11 articles (28.9%) base of tongue reduction for OSAS (with or without epiglottectomy or pharyngopalatoplasty), in 8 articles (21.1%) parapharyngeal space masses removal, in 5 articles (13.3%) excision of head and neck tumors in 4 articles (10.5%) submandibular sialoadenectomy, in 3 articles (7.9%) retropharyngeal space masses removal, in 3 articles (7.9%) tongue mucosectomy (TBM) to identify unknow primary tumor of head and neck, in 1 paper (2.6%) hilo-parenchymal submandibular stones removal, plunging ranula removal, styloidectomy in Eagle's Syndrome and upper alveolus angiomyxoma removal.

Table 1
Main features of the 38 included papers.

Author/Year	Country	Study Design	N°Cases	Surgical procedure/ Operative time	Outcomes	Complications	Robot
O'Malley[11] 2010	USA	Original Article	10 2M 8 F Age 53 y	Trans-oral robotic surgery to remove parapharyngeal space masses	The final pathologies were 7 pleomorphic adenomas and 3 benign cysts. No residual lesion or recurrence at 12 months of follow-up	Dehiscence of the mucosal incision (20%) Intraoperative tumor fragmentation (14%)	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Walvekar[12] 2011	USA	Case Report	1 F Age 47 y	Trans-oral robotic surgery to remove bilateral plunging ranula	No residual lesion or recurrence at 12 months of follow-up	No complications experienced.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Vidhyadharan[13] 2012	Australia	Case Report	1 M Age 56 y	Trans-oral robotic resection of a second branchial arch cyst in the right parapharyngeal space Time: no reported	MRI imaging of the neck 12 months post-operation revealed no residual or recurrence of the lesion.	minimal pain and neither trismus nor "first bite pain"	45° to operating table. Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Lee[14] 2012	South Korea	Case Series	2 1 M 19 y 1 M 31 y	Trans-oral robotic resection of neurogenic tumors of the prestyloid parapharyngeal space Time 1: 133 min Time 2: 94 min	No residual gland or recurrence at six months of follow-up. Advantages: magnified three-dimensional and direct view; prevented rupture or spillage of the tumor with clear identification of the capsule and delicate dissection using motion scaling.	No complications experienced.	30° to operating table. Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Rassekh[15] 2013	USA	Technical Note/ Guidelines	No rep.	Trans-oral robotic surgery to remove parapharyngeal space masses, defining indications and contraindications to procedure.	Indications: Prestyloid salivary gland tumors that do not extend through the stylomandibular tunnel or not involve significantly parotid, schwannomas neurofibromas and cysts, retropharyngeal space masses that do not invade or extend laterally to the carotid artery	Contraindications: poststyloid lesions that displace the carotid antero and medially, All paragangliomas, Osseous skull base involvement, malignant FNA, retropharyngeal masses encasing, lateral to or invasive of the carotid artery	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)

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Table 1 (*continued*)

Author/Year	Country	Study Design	N°Cases	Surgical procedure/ Operative time	Outcomes	Complications	Robot
Prosser[16] 2013	USA	Case Report	1 F Age 51 y	Trans-oral robotic submandibular sialoadenectomy, saving up the lingual nerve and the sublingual gland. Time: 95 minutes	No residual gland or recurrence at six months of follow-up. Advantages: excellent near-field visualization and three-dimensional magnification	The patient experienced transient lingual hypoesthesia which resolved over 4 weeks.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Capaccio[17] 2013	Italy	Technical Note	1 F Age 68 y	Trans-oral robotic submandibular sialoadenectomy, saving up the lingual nerve and the sublingual gland. Time: 100 minutes	No residual gland or recurrence at three months of follow-up. Advantages: excellent near-field visualization and three-dimensional magnification	No complications experienced.	30° to operating table. Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Moran[18] 2014	Israel	Original article	Not reported	Trans-oral robotic surgery to remove parapharyngeal space masses, defining indications and contraindications to procedure.	Contraindications include tumors located posterior to the great vessels (i.e.the internal carotid artery and internal jugular vein), involvement of the parotid gland (deep lobe or superficial lobe), intracranial involvement and malignance. Relative contraindications to TORS include inadequate oral exposure and limited cervical spine mobility	Not reported	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);
Goepfert[19] 2015	USA	Case Report	1 F Age 64 y	Trans-oral robotic excision of an isolated retropharyngeal lymph node metastasis of papillary thyroid carcinoma, performed under trans-oral ultrasound guide. Time: 45 minutes	At 2 months, the patient swallowing was normal with no further globus and no first-bite syndrome. At 2 months post-lymph node excision, the patient underwent a second course of RAI treatment with I-131, 125 mCi.	Dysphagia that solved with an appropriate diet.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)

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Table 1 (*continued*)

Author/Year	Country	Study Design	N°Cases	Surgical procedure/ Operative time	Outcomes	Complications	Robot
D'agostino[20] 2016	USA	Review	243	Patients with obstructive sleep apnea (OSA) who fail positive airway pressure (PAP) therapy (continuous PAP [CPAP], bilevel PAP [BiPAP], auto titrating CPAP [AutoPAP]) may be considered for oral appliance therapy or surgery.	The success rate, ≥50% reduction of pre-operative Apnea-hypopnea index, was 80% in TORS procedures. The TORS advantages include wide-field high-definition 3-D visualization, precise instrumentation, and when compared with open procedures, less operative time, quicker recovery, no external scars and comparable tissue resection.	The most common complications include bleeding (4.1%), dehydration (4.8%), and dysphagia (5.1%)	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);
Dutta[21] 2016	Nepal	Review	No rep.	Transoral robotic surgery in maxillofacial surgery. The review investigates the maxillofacial procedures robotic-assisted.	tongue base resection, tonsillectomy, soft palate resection, nasopharyngectomy, resection of parapharyngeal tumors, skull base surgery, transoral laser excision, treatment for sleep apnea, implant placement, anterior floor of mouth surgery, endoscopic sinus surgery, Robot-guided laser ostectomy.	No reported	- Robodoc system by Kavanagh - Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA) - Medrobotics Flex® system (Medrobotics Corp., Raynham, MA)
Heaton[22] 2016	USA	Case report	1 F 62 years	Transoral robotic surgery (TORS) for the excision of a retropharyngeal intramuscular lipoma. Time: 35 minutes	TORS is an effective, safe, feasible, and likely more efficient way to excise a retropharyngeal intramuscular lipoma or other retropharyngeal masses.	No complications experienced.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);
Cammaroto[23] 2017	Italy	Systematic Review	1082 Sex no rep. Age 49 y	Trans-oral robotic reduction of soft tissues for the treatment of obstructive sleep apneas (OSAHS) in adults, compared to Coblation tongue surgery. Time: no reported	TORS was used to perform palatopharyngoplasty (71%), Expansion sphincter pharyngoplasty (15%), Epiglottoplasty in association with robotic tongue base reduction (48%). The mean rates of failure were 34.4 and 38.5 %, respectively in TORS and Coblation groups. The mean rate of failure in TORS was 34.4%.	Complications occurred in 21% of TORS: Transient dysphagia in 7.2%, bleeding in 4.2 %, post-operative pharyngeal edema in 1%. Least reported events were: globus, transient dysgeusia.	No rep.

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Table 1 (*continued*)

Author/Year	Country	Study Design	N°Cases	Surgical procedure/ Operative time	Outcomes	Complications	Robot
Folk[24] 2017	USA	Original article	61 (45 in robotic surgery group). In TORS group: 33 M 12 F 48.2 y	TORS compared to endoscopic technique for midline glossectomy in obstructive sleep apnea hypopnea syndrome (OSAHS)	In the robotic surgery group there were statistically significant improvements in AHI, Epworth Sleepiness Scale, and O2 nadir. In the endoscopic group there were also improvements in AHI, Epworth Sleepiness Scale,and O2 nadir Surgical success rate was 75.6% and 56.3% in the robotic and endoscopic groups, respectively.	No intraoperative complications. Nine patients experienced postoperative complications: Four bleeding; One patient pneumonia and dehydration; Three other patients postoperative dehydration;	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);
Garas[25] 2017	UK	Systematic Review	311 223 M 88 F Age 52 y	Transoral Robotic Surgery (TORS) is a safe and effective multilevel treatment for Obstructive Sleep Apnea (OSA) in obese patients following failure of conventional treatment(s).	5 articles were considered for different surgical procedures: BOT reduction only BOT reduction plus UPPP BOT reduction plus epiglottectomy BOT reduction, plus epiglottectomy, plus UPPP The success rate (apnea-hypopnea index <20) was in all papers lower in obese patients	Complications reported in 2 papers: -minor secondary haemorrhage 7% -dysgeusia and tongue numbess 7% -odynophagia to solids 14% Voice and swallowing worsened initially in first 2 week	Not rep.
Vicini[26] 2017	Italy	Review	240 Sex and age no rep.	Transoral robotic surgery in OSAS patients: the performed procedures were tongue base reduction, both sides and supra-hyoid horizontal epiglottectomy. Time: no reported	The rate of success, defined as 50% reduction of pre-operative Apnea-hypopnea index, and an overall AHI<20 events/h, is achieved in up to 76.6% of patients with a range between 53.8% and 83.3%	-bleeding 4.2% -transient dysphagia 7.2% -Transient pharyngeal globus 0.4% -Transient pharyngeal edema 0.4% -Transient hypogeusia 14.4% -Pharyngeal stenosis 0.4%	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);

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Table 1 (*continued*)

Author/Year	Country	Study Design	N°Cases	Surgical procedure/ Operative time	Outcomes	Complications	Robot
Winter[27] 2017	United Kindom	Original Article	32 27 M 5 F Age 57 y	Trans-oral robotic assisted tongue base mucosectomy (TBM) to identify site of unknow primary tumor of head&neck Time: no reported	The primary tumor site was identified in the tongue base in 53% of patients. In 15 patients the tumor was ipsilateral (88%) while in two cases (12%) the tumor was contra lateral.	three (9%) patients developed complications: one postoperative chest infection and two others postoperative bleeding that settled with conservative treatment	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Bonnecaze[28] 2018	France	Original Article	8 5 M 3 F Age 47 y	Transoral robotic tongue base reduction in OSAS patients. In 4 patients associated procedures: 3 pharyngoplasties and 1 tonsillectomy. Average Time: 85 min.	Success rate 62.5% (apnea-hypopnea index <20). Improvement in BMI e body weight	12.5% taste disorder 12.5% pharyngeal paresthesia	30° to operating table. Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Cammaroto[29] 2018	Italy	Original Article	51 38 M 13 F Age 55 y	Transoral robotic tongue base reduction in OSAS patients Time: no reported	A success rate of 74.5% was recorded, with a statistically significant reduction of postoperative apnea-hypopnea index, not related to tongue volume reduction	No reported	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Fuglsang[30] 2018	Denmark	Case report	1 1 M 31 y	Transoral robotic surgery to remove a non-subclassified vascular malformation with a retropharyngeal location	Minimal residual lesion in the right side of the rhinopharynx at one month follow-up, unchanged at 6 months follow-up	No complications experienced.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);
Maglione[31] 2018	Italy	Case series	4 2 M 2 F 38 y	Transoral robotic surgery to facilitate the minimally invasive surgical approach parapharyngeal space benign tumors.	No residual or recurrence were observed	No complications experienced.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);
Vicini[32] 2018	Italy	Review	No rep.	Reporting the different surgery types that can be performed with a TORS approach for tongue base reduction surgery in patients with obstructive sleep apnea syndrome (OSAS)	Right-side lingual tonsillectomy Left-side lingual tonsillectomy Residual obstruction evaluation Additional resections of tongue base Supraglottoplasty	No reported	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);

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Table 1 (*continued*)

Author/Year	Country	Study Design	N°Cases	Surgical procedure/ Operative time	Outcomes	Complications	Robot
Capaccio[33] 2019	Italy	Case series	2 1 M 56 y 1 F 43 y	Transoral robotic surgery to remove hilo-parenchymal submandibular stones as alternative to traditional scialoadenectomy Average Time: 50 min	Neither residual stones nor duct dilation was observed on US evaluation at 3 months follow-up	Transitory pain in the female patient	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Lan[34] 2019	Taiwan	Original Article	33 28 M 5 F 39 y	Trans-oral robotic surgery vs coblation for tongue base reduction surgery in patients with obstructive sleep apnea syndrome (OSAS).	16 patients TORS and 17 coblation surgery, both with uvulopalatoplasty. The success rate, ≥50% reduction of pre-operative Apnea-hypopnea index, in the TORS and coblation group were 50% and 58%, respectively	Minor complications, including transient dysphagia, pharyngeal edema and dysgeusia were higher in the TORS group (50%) than the coblation group (35.3%)	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Lin[35] 2019	China	Case Report	1 F Age 32 y	Trans-oral robotic submandibular sialoadenectomy, saving up the Warthon duct and the sublingual gland. Time: 160 minutes	No residual gland or recurrence at three months of follow-up.	Edema and transient deficit of lingual nerve.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Meccariello[36] 2019	Italy	Systematic Review	349 281 M 68 F	Trans-oral robotic surgery to detect primary tumor in unknown primary of the head and neck	12 articles: The total PT detection rate was 70.8% (64% base of tongue, 28.7% palatine tonsils, 7.3% oropharynge and hipopharynge). The total rate of positive margins was 22.8%.	hemorrhage (2.4%), fistula (2.5%), and gastrostomy tubes at the time of surgery (1.4%)	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Sethi[37] 2019	Australia	Original Article	20 14 M 6 F Age 57 y	Experience of transoral robotic surgery with the new Medrobotics Flex® system to remove base of tongue cancers, to identify unknow primary tumors, or to treat tonsillitis. Time: no reported	9 patients (45%) were treated for benign pathologies, 8 (40%) for base of tongue cancers (glossectomy, partial glossectomy or excision) and 3 (15%) for tongue mucosectomy to identify unknow primary tumors (1 cancer, 1 sarcoma, 1 likely cutaneous primary)	2 post-operative complications (10%): one secondary haemorrhage at day 13 post-operatively, and one oro-cervical fistula.	Medrobotics Flex® system (Medrobotics Corp., Raynham, MA)

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Table 1 (*continued*)

Author/Year	Country	Study Design	N°Cases	Surgical procedure/ Operative time	Outcomes	Complications	Robot
Cammaroto[38] 2020	Italy	Systematic Review	681 Age and sex no rep.	Trans-oral robotic surgery in the management of benign and functional pathologies of the head and neck	100 articles: 1 oral cavity, 37 oropharynx (Base of tongue reduction; Foreign body removal; Lingual thyroid resection and cyst excision), 7 hypopharynx, 11 larynx, 21 parapharyngeal and retropharyngeal spaces, 6 sublingual and submandibular glands, 5 thyroid space, 1 sella turcica (pituitary adenomas) and 11 reconstructive surgery (Reconstruction post-oropharyngectomy; palatal and laryngeal cleft repair; palatoplasty)	Limitations to use TORS - Elevated costs - lack of dedicated equipment for head and neck surgery - elongation of surgical times, especially with the set up and the docking phase of the surgery - long learning curve for young surgeons	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA); Medrobotics Flex® system (Medrobotics Corp., Raynham, MA) % no reported
Lin[39] 2020		Review	106 Sex and age no rep.	Trans-oral robotic surgery in OSAS patients: base of tongue reduction, partial epiglottidectomy. Time: no reported	Average success rate: 61% (the more adeguate volume to resect is 7 ml) Improvement in breathing and pressure ($p<0.001$)	30% bleeding 1.7-5% second surgery for hemostatic; Minor complications reported: dysphagia, oropharyngeal adhesions and stenosis, tongue numbness, dysgeusia	30°-45° to operating table. Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
De Virgilio[40] 2020	Italy	Systematic Review	112 66 M 46 F Age 53 y	Trans-oral robotic surgery to remove parapharyngeal space masses. Time of: -Median robotic setup 8.95 min -median TORS procedure 102.5 min -median total surgery 147.3 min	22 articles: total tumors 113 (102 benign, 11 malignant); tumors successfully resected 98.2%. TORS procedure alone 83.3%, while combined trans-cervical (TORS-TC) and trans-parotid (TORS-TP) approaches 11.5% and 4.4% of patients, respectively. TORS assisted by tumor coblation to reduce the mass volume 1.8%. Capsule disruption during tumor dissection 14.5%; tumor fragmentation 10.3%.	dysphagia (4.5%), hematoma/secondary hemorrhage (3.6%), Horner's syndrome (2.7%), pharyngeal dehiscence (1.8%), trismus (1.8%), first bite syndrome (1.8%), vocal cord palsy/ laryngeal paralysis (1.8%), phlegmon (0.9%) and cervical emphysema (0.9%). Only 1 recurrence.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA); Medrobotics Flex® system (Medrobotics Corp., Raynham, MA) % no reported

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Table 1 (*continued*)

Author/Year	Country	Study Design	N°Cases	Surgical procedure/ Operative time	Outcomes	Complications	Robot
Fitzpatrick[41] 2020	USA	Original Article	19 15 F 4 M Age 48 y	Trans-oral robotic surgery to perform styloidectomy in Eagle's Syndrome, compared to transcervical approach Average Time: 98 min	On 19 patients, 6 TORS vs 13 transcervical: of TORS patients, 100% reported some degree of lasting symptomatic improvement and 66% reported significant improvement.	No complications for TORS patients, compared to transcervical approach (20%).	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Ionna[42] 2020	Italy	Original Article	67 45 M 22 F Age 52 y	Trans-oral robotic surgery to remove Head and Neck tumors. Average Time: 65 min	3 subsites: supraglottic larynx (27%), parapharyngeal space (7%) and oropharynx (66%) Confirmed malignancis in 44 cases: 12% lymphomas, 36 Squamous cell carcinoma 54%, benign salivary glands tumors 7% and miscellaneous 27%. In the cases of SCC, positive margins in 14 cases and close resection margins in 10 cases.	post-operative bleeding 4.5%, exitus for massive bleeding 20 days postsurgery 1.5%, respiratory failure treated with tracheotomy 1.5%.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);
Moffa[43] 2020	Italy	Case Report	1 F Age 23 y	Trans-oral robotic surgery to remove an Head and Neck tumor. Average Time: 120 min	No residual gland or recurrence at one year of follow-up.	No complications experienced.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Huang[44] 2021	Australia	Original Article	42 30 M 12 F Age 60 y	Trans-oral robotic surgery to remove Head and Neck tumors	Primary lesion site: Base of tongue 47.6%, Tonsil 40.5%, Larynx 7.1%, Parapharyngeal 4.8%, Pathology: Squamous cell carcinoma 45.2%, Benign 50%, Basosquamous carcinoma 4.8%. Positive margin 4.8%. Recurrence 4.8%.	Post-operative bleeding 4.8% Wound Infection/ dehiscence 4.8% Drain dislodgment 2.4% Fistula 2.4% Reintervention 9.5%	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);
Nair[45] 2021	India	Case report	1 M Age 45 y	Transoral robotic surgery for the removal of a large upper alveolus angiomyxoma of about 8 cm, occupying the oral cavity, eroding the adjacent hard palate and extending into the maxillary sinus	Complete removal of the tumor without recurrence at 6 months follow-up	Palatal defects solved with an obturator prothesis in 4 weeks.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);

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Table 1 (*continued*)

Author/Year	Country	Study Design	N°Cases	Surgical procedure/ Operative time	Outcomes	Complications	Robot
Peng[46] 2022	Taiwan	Original Article	48 M	Trans-oral robotic surgery in OSAS patients: base of tongue reduction, partial epiglottidectomy. Time: no reported	Successful rate (evaluated as postoperative Apnea-Hypopnea Index < 20/hour) was 45.8%. In the successful patients, there was also an improvement in body mass index, nicturia, erectile disfunction and in general quality of life.	No complications experienced.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);
Salzano[47] 2022	Italy	Original Article	14 5M 9F Age 48 y	Trans-oral robotic surgery to remove pleomorphic adenomas of the parapharyngeal space. Time: 95 minutes	Only 1 case of rupture of the capsule. No recurrence or residual lesion on MRI at 6 months follow-up.	No complications experienced.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);
Rogalska[48] 2023	Poland	Systematic review	99 No rep. Sex and age	Transoral robotic surgery (TORS) in the management of submandibular gland (SMG) sialolithiasis. Average Time: 91 min	80 patients TORS followed by sialendoscopy (TS); 11 patients sialendoscopy followed by TORS and sialendoscopy (STS); 4 patients sialendoscopy followed by TORS only (ST); and 4 patients underwent TORS only (T). The mean procedure success rate reached 94.97%, with the highest for ST 100% and T 100%, followed by the TS 95.04% and STS 90.91%.	Transient lingual nerve injury occurred in 28 patients (28.3%)	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA);

Table 2
Interesting articles about robotic-assisted procedures in maxillofacial surgery but not following the inclusion criteria of the systematic review.

Author/ Year	Country	Study Design	Specimen	Procedure	Objectives	Robotic system
Guo[49] 2016	China	Technical Note	On animals	Robotic-assisted mandibular osteotomies. The robot can move smoothly and do accurate placement of bone graft and aid fixation.	Robot-assisted surgery (RAS) system consisting in three parts: computer-aided design (CAD) system for CMF surgery, surgical robot for CMF surgery, and medical experiment for the CAD and robot. Its three arms can coordinate well to aid bone graft placement for different types of mandibular defects.	Integrated Surgical System Company, called ROBODOC system
Khan[50] 2016	United Kindom	Technical Note	On cadavers	Trans-oral robotic cleft surgery (TORCS) for palate and posterior pharyngeal wall reconstruction	To investigate the technical feasibility of trans-oral robotic cleft surgery (TORCS) to access the posterior pharyngeal wall and palate for potential use in the cleft population.	Si Da Vinci surgical robot (Intuitive Surgical, Sunnyvale, CA, USA)
Cao[51] 2019	China	Technical Note	On phantom	Robotic-assisted placement of zygomatic implants	To demonstrate how the accuracy of robotic operation is improved compared to manual placement of zygomatic implants.	UR robot (Universal Robots, Odense, Denmark)
Han[52] 2020	Korea	Technical Note	On phantom	A Robot Arm and Image-Guided Navigation Assisted Surgical System for Maxillary Repositioning in Orthognathic Surgery.	To identify and remove bone interferences and reposition the bone segments with improved accuracy and safety during orthognathic surgery. In contrast to traditional methods using intermediate splints, repositioning errors caused by the mandibular autorotation or the patient's condylar condition can be prevented.	The robot arm and navigation assisted system (Cyborg-Lab, Suwon, Korea). The robot motion controller provided from the manufacturer (Precise Automation, Fremont, CA, USA)
Xiao[53] 2020	Singapore	Technical Note	On phantom	Trans-oral Robotic-Assisted Needle Direct Tracheostomy Puncture in Patients Requiring Prolonged Mechanical Ventilation	Flexible mini-robotic system, incorporating the robotic needling technology, to improve current Percutaneous Tracheostomy technology by making the initial trachea puncture from an "inside-out" approach	Microcontroller Arduino due, fiber optic Teed KTM-V2-25 mm, Dongguan Jingbiao Electronic Technology Co. Ltd, China
Han[54] 2021	Korea	Technical Note	On phantom	Robotic and navigation assisted maxillary repositioning in orthognathic surgery.	Using robot arms and navigation system maintain the maxillary segment in the target position during the fixation bone period. The maxilla exhibited a displacement of 0.22 mm, 0.18 mm, and 0.18 mm in medio-lateral, antero-posterior, and supero-inferior directions, respectively, compared to virtual planning.	The robot arm and navigation assisted system (Cyborg-Lab, Suwon, Korea). The robot motion controller provided from the manufacturer (Precise Automation, Fremont, CA, USA)

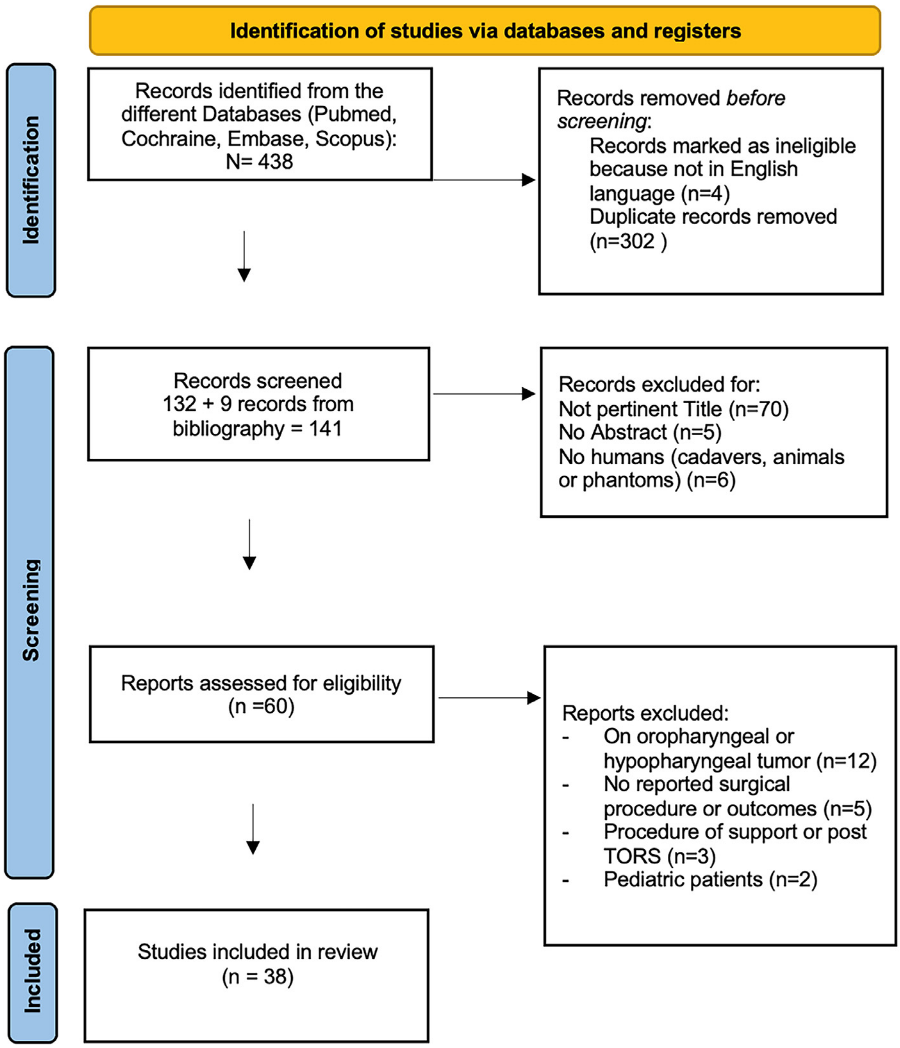

Figure 1. PRISMA 2020 flow diagram for new systematic reviews.

Procedures Duration Time

Procedure duration time was reported in 14 studies: the mean operative time for submandibular sialoadenectomy was 99 minutes (range 50-160 min), for parapharyngeal space masses removal 117.5 min (range 94-147.5 min), for retropharyngeal space masses removal 40 min (range 35-45 min), for styloidectomy in Eagle's Syndrome 98 min, for the excision of head and neck tumors 92.5 min (range 65-120 min), for base of tongue reduction for OSAS 85 min, for hilo-parenchymal submandibular stones removal 50 min.

Procedures Success Rate

Procedural success rate was described in all the studies. For unknown primary tumors detection the mean success rate was 61.9%; for parapharyngeal space masses removal was 75.8%;

for submandibular sialoadenectomy was 95%; for OSAS correction surgery was 65.7%; for Eagle's Syndrome treatment was 66%.

In head and neck tumors excision, the following outcomes were considered: mean rate of positive margins 17.3%, mean intraoperative tumor fragmentation 12.4%, mean rate of intraoperative capsule disruption 10.8%, mean rate of recurrence 4.8%.

Complications

The postoperative complications were reported in 25 papers (65.8%); in 9 articles (23.7%) no complications occurred while in 4 papers (10.5%) complications were no reported. The experienced complications were: transient lingual nerve disorders with dysgeusia/hypogeusia (13.3%), dysphagia (7.4%), wounds dehiscences (5.5%), bleeding/ secondary hemorrhage (5.4%), dehydration (5.2%), fistulas (2.7%) and post-operative pharyngeal disorders, such as edema, stenosis, globus and paresthesia (1.2%). Other minor complications ($<1\%$) were pain, first bite syndrome, trismus, Horner's syndrome, vocal cord palsy/ laryngeal paralysis, phlegmon and cervical emphysema. Only one exitus for massive bleeding and one respiratory failure treated with tracheotomy were reported.

Type of Robot

Si Da Vinci surgical robot was used in 32 studies (84.2%); in 3 studies (7.9%) different type of robot were employed (Si Da Vinci surgical robot, Robodoc system by Kavanagh and Medrobotics Flex® system); in 1 study (2.6%) only the Medrobotics Flex® system was used while in others 2 (5.3%) studies the type of robot was not reported.

Data Analysis of the six interesting papers excluded from the systematic review

The general features of these interesting papers are shown in Table 2. Two studies were performed in China, two in Korea, one in United Kindom and one in Singapore. All the studies were technical notes/experiments: four studies were conducted on phantoms, one on animals and one on cadaveric specimens. In three studies experiments of robotic-assisted surgery were performed on maxillary and mandibular osteotomies for repositioning in orthognathic surgery; in one study robotic-assisted surgery was employed for zygomatic implants placement; in one study for needle direct tracheostomy puncture and in one study for palate and posterior pharyngeal wall reconstruction in cleft population. In these articles different robotic systems were used: in particular in 2 studies the Cyborg-Lab robot system, in one study the Universal Robot system, in one study the Si Da Vinci system, in one study the ROBODOC system and in another study Dongguan Jingbiao Electronic system.

Discussion

The use of robotic surgery in maxillofacial surgery is a topic that has fascinated many authors in recent years. One of the most complete reviews on the topic was published by De Ceulaer et al[55] in 2012 and highlighted how robotic surgery was very useful for the treatment of oral and cervical soft tissues pathologies, revealing excellent outcomes in terms of success rate of the procedures and reduction of complications, compared to traditional surgery. Other several Authors[56,57] have confirmed these results highlighting the advantages of the procedure, such as no external incision, better field of visualization, avoiding mandibulotomy or maxillectomy;

three-dimensionality providing better depth perception of anatomical structures and their relations; the possibility of an efficient four-handed surgery; the presence of motion scaling and tremor filtration technology, which avoids dangerous movements, allowing precise tissue dissection; no neck dissection or neck drain, no division of stylomandibular ligament or digastric, no dissection or retraction or monitoring of cranial nerves, reduced first-bite syndrome, reduced trismus and mandibular pain due to decreased retraction and muscle dissection or division.[13-15] Another significant advantage of robotic surgery is the benefit of improved surgical ergonomics: a comfortable seated position and decreased prolonged neck strain might reduce the frequency of work-related musculoskeletal disorders among ENT specialists and ultimately lead to the increased career length of a head and neck surgeon.[48] These advantages are mainly exploited in the treatment of lesions of the parapharyngeal space, removal of benign and malignant tumors of the oropharynx, hypopharynx and base of the tongue up to Eagle's syndrome for removal of calcific styloid processes.[8,9,11,40,41]

Despite many advantages, some contraindications have been recognized, such as tumor resection requiring $>$50% of deep tongue base musculature or posterior oropharyngeal wall, trismus, cervical spine disease limiting appropriate patient positioning, tonsillar tumor with a retropharyngeal course of the internal carotid artery/arteries, medialized carotid artery lying adjacent to tonsil, elevated costs, lack of dedicated equipment for head and neck surgery, elongation of surgical times, especially with the set up and the docking phase of the surgery and the long learning curve for young surgeons.[15,58]

Thus, the usefulness of this approach on soft tissues has been universally accepted by scientific literature, while an evaluation of its use for hard tissue pathologies, in particular of maxillofacial relevance, is still under study. Hence, the desire of the Authors of this paper to focus a systematic review of literature on the uses of TORS on head and neck hard tissues. The interesting thing that emerges from this review is that until August 2023, no clinical trials have been conducted on patients, only experiment paper on cadaver, animals, or phantoms. Therefore, these papers were analyzed for their relevance and encouraging results, although they were excluded from the review because they did not meet the inclusion criteria.

The first articles about the use of robotic surgery for hard tissues pathologies were written since the 2000s: regarding orthognathic surgery, Engel et al[59] introduced the RobaCKa robotic system for performing osteotomies in jaw, mouth and facial surgery; Gui et al[60] developed a robotic system to perform Le Fort I osteotomies; Lijima et al[61] and Woo et al[62] developed a robotic system to improve orthognathic surgery and an image-guided virtual planning system to transfer the preoperative virtual plan into the intraoperative phase of orthognathic surgery. The TORS approach to orthognathic surgery is currently being studied: Guo et al[49] conducted preclinical studies on animals and developed a system to improve the fixation and the placement of bone graft after orthognathic surgery, while Han et al[52,54] conducted preclinical studies on phantoms and developed a system to identify and remove bone interferences and reposition the bone segments with improved accuracy and safety.

Regarding dental implant surgery, the first articles were written since the 2000s: Sun et al[63] developed a system to assist the surgeon during implant osteotomy site preparation by holding a drilling guide; Kasahara et al[64] and Syed et al[65] developed a telerobotic system that provides a visual and physical guide in the planning and surgical phases of dental implant surgery, helping the surgeon with position, depth, and angulation. However, tactile feedback of force and depth to apply is crucial in implant surgery, thus the transoral robotic approach is currently being studied. In particular, several experiments on phantom are being conducted for zygomatic implants placement, comparing the accuracy between the robotic system and the manual positioning.[51]

Moreover, transoral robotic approach is under study also to perform a tracheotomy puncture from the inside, such as percutaneous endotracheal tracheotomy[53] and to reconstruct palate and posterior pharyngeal wall in cleft population.[50]

These preclinical studies have shown that where tactile feedback and perception is necessary for successful surgery, robotic approach fails. For this reason, in traumatology, the prospects of using robotic technology are still far away: in fact, the treatment of maxillofacial fractures results more difficult than in other regions both because the position of segments changes before and after reduction, making the navigation imprecise, and because it is impossible to provide appropriate resistance during the fixation.[66]

Thus, this systematic review reveals that while for hard tissues diseases management there are still studies to be conducted, for the treatment of soft tissue diseases TORS appears to be a valid and effective approach. In particular, the recorded procedural success rate was 61.9% for unknown primary tumors detection, 95% for submandibular sialoadenectomy, 75.8% for parapharyngeal space masses removal, 65.7% for OSAS correction surgery and 66% for Eagle's Syndrome treatment.

In head and neck tumors excision, the following outcomes were considered: mean rate of positive margins 17.3%, mean intraoperative tumor fragmentation 12.4%, mean rate of intraoperative capsule disruption 10.8%, mean rate of recurrence 4.8%.

The recorded complications with TORS were: transient lingual nerve disorders with dysgeusia/hypogeusia (13.3%), dysphagia (7.4%), wounds dehiscences (5.5%), bleeding/ secondary hemorrhage (5.4%), dehydration (5.2%), fistulas (2.7%) and post-operative pharyngeal disorders, such as edema, stenosis, globus and paresthesia (1.2%).

Regarding the operative time, the mean surgical time for submandibular sialoadenectomy was 99 minutes for parapharyngeal space masses removal 117.5 min, for retropharyngeal space masses removal 40 min, for styloidectomy in Eagle's Syndrome 98 min, for the excision of head and neck tumors 92.5 min, for base of tongue reduction for OSAS 85 min.

Therefore, for a less invasive surgery, the trade-off is the presence of different limitations of using this approach: an increased bleeding risk, a prolonged surgical time, a long learning curve and a high cost, $1 million dollars for the system purchase and $100,000/year for robotic instrumentation maintenance.[67]

Anyway, the future perspectives are: the widespread of the system and consequentially the reduction of the costs; the setting up of surgical training workshops to speed up the learning curve of the technique; and the performance of comparative prospective studies.

Conclusion

Data obtained from this systematic review seem to confirm that TORS is a valid tool for the treatment of soft tissue pathologies also of maxillofacial pertinence. The effectiveness of this approach on the hard tissues of the maxillofacial district is still being studied, but the most promising results have been obtained for orthognathic surgery and implantology. However, in maxillofacial traumatology, given the mobility of the fractured bone tissues and the high tactile feedback required for fracture reduction, this approach does not seem preferable. Anyway, the future perspective is to carry out comparative prospective studies.

Data availability statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study (systematic review).

Institutional Review Board Statement

Ethical review and approval were waived for this study due to the nature of systematic review.

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Conflict of Interests

The Authors declare no conflict of interests.

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Stefania Troise: Conceptualization. **Antonio Arena:** Writing – original draft. **Simona Barone:** Writing – original draft. **Luca Raccampo:** Data curation. **Giovanni Salzano:** Data curation. **Vincenzo Abbate:** Data curation. **Paola Bonavolontà:** Data curation. **Antonio Romano:** Data curation. **Salvatore Sembronio:** Data curation. **Massimo Robiony:** Supervision. **Luigi Califano:** Supervision. **Giovanni Dell'Aversana Orabona:** final approval.

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