REVIEW ARTICLE

The Role of Robotic Surgery in Benign Otolaryngology Head and Neck Surgery: A Systematic Review of the Literature.

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Abstract

The role of robotic-assisted surgery has increased exponentially in many surgical specialities over recent years. However, common usage within otolaryngology still appears limited. We aim to explore the alternative uses for robot-assisted surgery in benign otolaryngology, head and neck pathologies.

A systematic review of the literature was performed by searching electronic databases and references libraries.

2485 papers were identified through our search. 96 studies met our inclusion criteria. Our results are categorized and displayed in table format.

There are multiple novel adaptations of robotic-assisted surgery being performed across the world in benign otolaryngology, head and neck pathologies. Exciting advances in technology and availability will expand this scope even further in the near future.

1. Introduction

Robotics has been an area of intrigue and wonder dreamt of by many a visionary and utilised by cutting edge industries since the days of Leonardo DaVinci[1]. In 1985 the first robotic-assisted surgery was performed to assist in directing the trajectory of a stereotactic brain biopsy[2]. Since this pioneering procedure, the applications of robotic surgery have increased exponentially. However, within the speciality of otolaryngology, head and neck surgery, common usage has not become standardised and appears restricted to specialized centres limited to a small number of malignant pathologies. With increasing technological advances, availability, and declining cost of production by multiple private industries, we sought to explore the alternative uses for robot-assisted surgery in benign otolaryngology, head and neck pathologies.

2. Methods

We performed a systematic review of the literature by searching the following electronic databases to identify relevant papers: MEDLINE PubMed, The Cochrane Central Register of Controlled trials (CENTRAL), Ovid MEDLINE, EMBASE, Scopus. Our main MeSH headings were as follows: otolaryngology, head and neck, multiple anatomical locations, robot, TORS/ transoral robotic surgery.

Studies suitable for inclusion included systematic reviews or previous meta-analyses, randomised controlled trials and non-randomised comparison studies irrespective of publication status, year of publication or sample size. If papers of this description were not available, a synopsis of case reports and case series was performed, including people of any age and sex who underwent robotic surgery for non-malignant pathologies in the head and neck.

Since it was not in line with our primary goal, studies involving head and neck malignancies were excluded. This is due to the large numbers of systematic reviews that have been previously published on the topic, aiding the ongoing debate surrounding its use. Studies were limited to those published in English or those for which a full translation was available. We also excluded studies that involved cadaveric or model specimens.

Two authors independently reviewed all search results by scanning titles and abstracts to identify articles that required full text review. The full text was reviewed before deciding whether an article was suitable for inclusion. Any conflicts between the review authors were settled by open discussion, and ongoing disagreements were resolved by a third person when necessary. Additionally, bibliographies and citations of all identified studies were searched to ensure no papers were missed. All studies identified were stored using the EndNote x7.8 programme.

To fulfil the aim of this systematic review, the primary outcome investigated was complete resection and disease free follow-up. Secondary outcomes that were investigated included complications as reported by individual authors.

The methodological quality and risk of bias for the studies we selected were assessed and analysed according to the way in which the data points were collected. The Cochrane Collaboration's tool for assessing the risk of bias in RCT, The Risk Of Bias In Non-randomised Studies - of Interventions (ROBINS-I) tool or the Joanna Briggs Institute Critical Appraisal Checklist for Case

Reports was used as appropriate. Papers scoring very high risk were excluded.

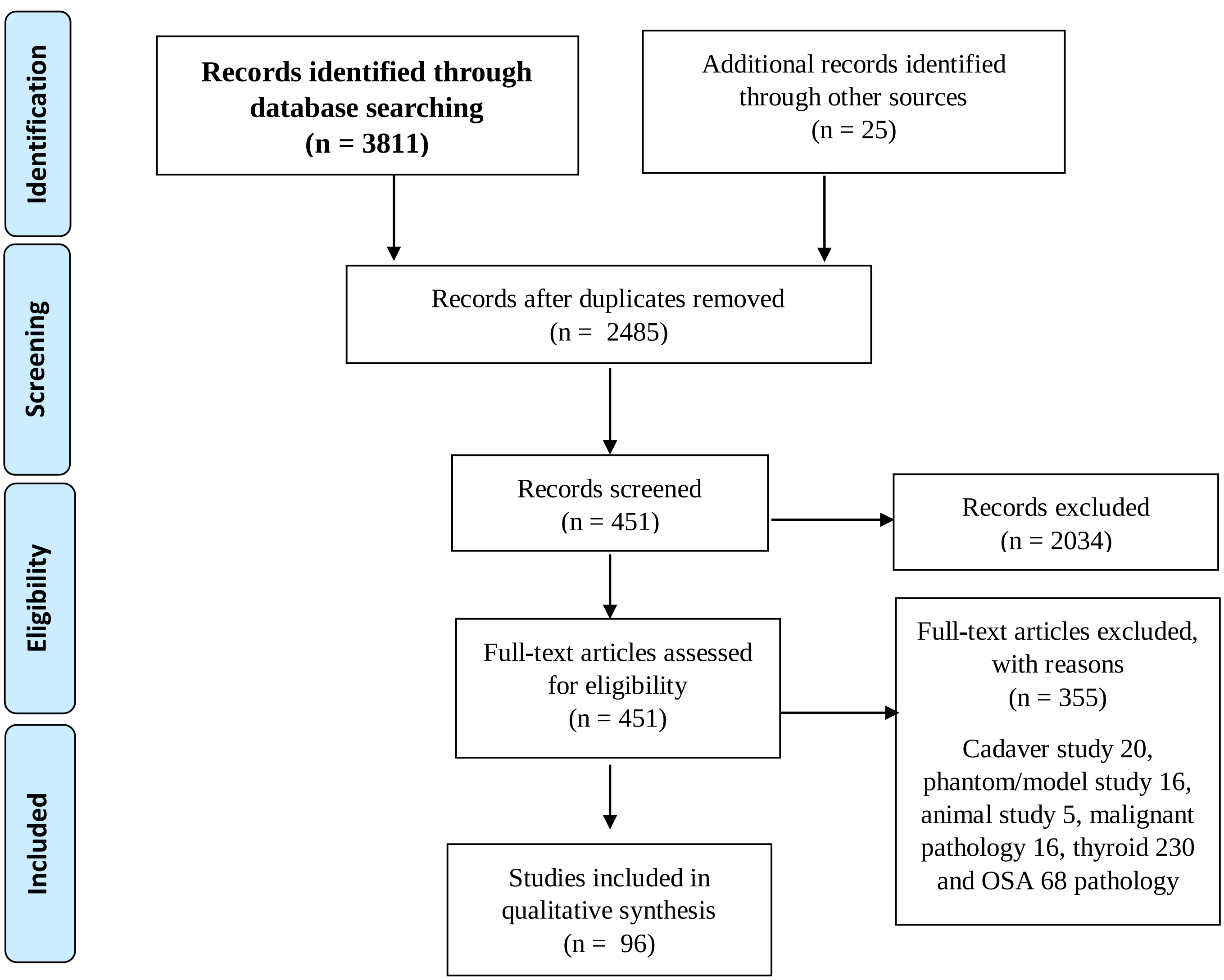
3. Results

3.1 Results of the search

We identified a total of 2485 papers through electronic searches and our bibliography search. Irrelevant papers were excluded after reading titles and abstracts. 451 papers required full text review for detailed assessment. 344 of these papers were eventually excluded as they did not meet our inclusion criteria. 96 studies met our inclusion criteria and were included in this review. Our filtering process is summarised in the PRISMA flow diagram (Figure 1).

By categorizing the papers we identified 15 common topics – thyroid, lingual thyroid, obstructive sleep apnoea (OSA), benign neck mass, laryngeal, pharyngeal, thyroglossal duct cyst, cochlear, endonasal, plastics, orbital, vascular, salivary, eagles syndrome, removal of foreign body.

Fig 1: PRISMA flow diagram.



The most common topics Thyroid surgery[3, 4] and OSA[5, 6] have been already well investigated and documented with several recent systematic reviews and meta-analysis published. Therefore we decided to focus on the more novel areas of usage so these papers were excluded.

3.2 Table of results

Pathology	Paper	Study type	Number of participants	Primary outcomes	Secondary outcomes
Cochlear	Caversaccio et al, 2017 Caversaccio et al, 2019 Daoudi et al, 2012 Jia H, et al, 2020	Case report Case series Case control Case report	1 9 20 /60 1 total 31	Successful robotic tunnel drilling. Satisfactory placement in all tympani 25, vestibule 6	No facial nerve injury
Congenital neck lump	Ahn et al, 2017 Fanous et al, 2020 Lin et al, 2016 Park et al, 2013 Rassekh et al, 2015 Song et al, 2015 Venkatakarthikeyan et al, 2020 Vidhyadharan et al, 2012	Case series Case report Case report Case series Case report Case series Case series Case report	23 1 1 9 1 3 2/3 1 total 41	Complete resection No recurrence at 3 month - 2 year follow up	1 haematoma 3 transient angle of the mouth weakness 1 seroma
Eagle's Syndrome	Kamil et al, 2015 Kim DH et al, 2017 Rizzo-Riera et al, 2020 Montevecchi F. 2019	Case report Case series Case series Case report	1 4 6 1 total 12	Successful resection Disease free at 1-3 month follow up	
Foreign Body	Karatayli Ozgursoy et al, 2020 Strohl et al, 2018	Case report Case series	1 2 total 3	Successful removal of foreign body No follow up	
Laryngeal airway	Ferrell et al, 2014 Rahbar et al, 2007 Zdanski et al, 2017 Erkul et al, 2017	Case series Case series Case series Case series	3 5 7/16 8/37 total 23	Satisfactory cleft repair Asymptomatic at 20-22 month follow up Not reported in one study	3 unsuccessful (limited transoral access) 1 reintubation 1 pneumonia 1 delayed extubation 1 mucosal trauma
	Hemmerling et al, 2012	Case series	12	Successful intubation 11/12 cases	1 unsuccessful (fogging)
	Montevecchi et al, 2017	Case series	4	Successful decannulation of tracheostomy	

				Asymptomatic at 6 month follow up	
	Wright et al, 2009	Case report	1	Successful re innervation of recurrent laryngeal nerve	
	Alessandrini et al, 2008 Remacle et al, 2018	Case series Case series	20 4 total 24	Successful visualisation of surgical field in 21/24 cases	2 short necks 1 prominent teeth
Upper aerodigestive tract benign tumors	Adkins et al, 2013 Chabrillac et al, 2018 Arnold et al, 2018 Kayhan et al, 2012 Kayhan et al, 2011 Millas et al, 2015 Cadena et al, 2018 Cadena et al, 2018 McLeod et al, 2005 Zdanski et al, 2017 Tan Weng Shen et al, 2018	Case report Case series Case report Case report Case report Case report Case report Case report Case report Case series Case report	1 6/21 1 1 1 1 1 1 1 7/16 1 total 21	Complete resection of lesion - lipoma, neruofibroma, parapharyngeal pleomorphic adenoma, paraganglioma, schwannoma, vallecular cyst, oncocytic cyst, lymphatic malformation, papilloma No recurrence at 1-24 month follow up in all except neurofibroma report	1 right vocal cord paresis 1 trismus 1 haematoma 1 dysphagia 1 aspiration 1 bleed 1 reintubation 1 pneumonia 1 delayed extubation
Laryngocele	Ciabatti et al, 2013 Gal et al, 2017 Kayhan et al, 2016 Lisan et al, 2016 Patel et al, 2019 Villeneuve et al, 2016	Case report Case report Case series Case report Case report Case series	1 1 6 1 1 8 total 20	Full resection of laryngocele No recurrence at 1-6 month follow up 1 case no follow up	1 haemorrhage
Lingual Thyroid	Dallan et al, 2013 Ersoy Callioglu et al, 2015 Howard et al, 2014 Kayhan et al, 2017 Kim et al, 2012 May et al, 2011 Park et al, 2013 Pellini et al, 2013 Prisman et al, 2015 Teo et al, 2013 Van Abel et al, 2011	Case report Case report Case series Case series Case series Case report Case series Case report Case series Case report Case report	1 1 9 4/8 3 1 3 1 3 1 1 total 28	Full resection of lingual thyroid No recurrence at 2 – 12 month follow up. 1 case no follow up	3 minor bleeding 1 epiglottic perforation 1 angioedema 1 transient numbness of the anterior ⅔ of the tongue

Lipoma	Heaton et al, 2016 Longo et al, 2016 Mendelsohn et al, 2014	Case report Case series Case report	1 1/4 1 total 3	Full resection of lipoma No recurrence at 6-12 month follow up	1 conversion to open
Nasolacrimal duct	Boehm et al, 2020	Case series	2	Successful dilatation Asymptomatic at 1 month follow up	
Pharyngeal stricture	Byrd et al, 2014 Miller et al, 2018 Zdanski et al, 2017	Case series Case report Case series	5 1 2/16 total 8	Successful dilatation in all cases No residual symptoms at 1 year follow up	
Pharyngeal stricture **Plastics/** **cleft palate**	Byrd et al, 2014 Miller et al, 2018 Zdanski et al, 2017 Klein et al, 2001	Case series Case report Case series Case series	5 1 2/16 total 8 13	Successful dilatation in all cases No residual symptoms at 1 year follow up Satisfactory ear reconstruction implant	
Plastics/ **cleft palate** **Pleomorphic adenoma**	Leonardis et al, 2014 Nadjmi et al, 2016	Case series Case series	5 10/30 total 15	Satisfactory cleft repair 1-8 month follow up	Longer operative time 1 mucosal dehiscence
	Ahn et al, 2017 Boyce et al, 2016 Chan et al, 2014 De Virgilio et al 2012 Kim GG et al, 2012 Longo et al, 2016 Moffa et al, 2020 O'Malley et al 2010 Park et al 2013 Samoy et al, 2015 Yang et al, 2014	Case series Case series Case Series Case series Case series Case series Case report Case series Case series Case series Cases series	10/23 11/16 2/4 8/10 2 3/4 1 3/10 11 4 4 total 66	Full resection No recurrence at follow up 3-19 months	2 haematoma 3 transient angle of the mouth weakness 1 seroma 1 phlegmon 1 trismus 6 conversion to open
Sialadenitis/ benign salivary	Capaccio et al, 2020 Capaccio et al, 2019 Carey et al, 2017 Frost et al, 2020 Koc et al, 2016 Park et al, 2013 Prosser et al, 2013 Venkatakarthikeyan et al, 2020	Case report Case series Case report Case report Case report Case series Case report Case series	1 2 1 1 1 3 1 1/3	Removal of stone/gland Disease free follow up 3-12 months. One paper no follow-up reported	

	Walvekar et al, 2011	Case report	1 total 12		
Parapharyngeal Schwannoma	Ansarin et al, 2014 Boyce et al, 2016 De Virgilio et al 2012 Gungadeen et al, 2016 Kayhan et al, 2011 Lee et al, 2012 Millas et al, 2015 Petruzzi et al, 2020 Samoy et al, 2015	Case series Case series Case series Case report Case report Case series Case report Case report Case series	2 1/9 2/10 1 1 2 1 1 1/4 total11	Full resection of schwannoma No recurrence at follow up 1-14 months	1 Horner's Syndrome 1 first bite syndrome 1 conversion to open
Endonasal	Li et al, 2020	Case series	20	Adequate nasal swab in all cases	Sore throat
	Okuda et al, 2020	Case series	18	Successful visualisation of surgical area in all FESS cases	
	Sreenath et al, 2014	Case series	1/3	Successful nasopharyngectomy (cocaine stricture) asymptomatic at follow up	Transient velopharyngeal insufficiency
	Zalzal et al, 2020	Case report	1	Partial resection of juvenile angiofibroma 3 month follow up showed residual mass in Meckel's cave	
Thyroglossal duct cyst	Carroll et al, 2016 Fong et al, 2018 Johnston et al, 2020 Kayhan et al, 2017 Kim et al, 2014 Kimple et al. 2012 Lee et. Al, 2020 Turhan et al, 2019 Turri-Zanoni et al, 2018	Case report Case report Case series Case series case report Case Report Case Series Case report Case report	1 1 2 4/8 1 1 6 1 1 total 18	Complete resection TGDC No recurrence at 2 weeks-2 years follow up	1 minor bleed 1 transient marginal nerve palsy 1 seroma
Vascular tumour/ malformation	Boyce et al, 2016 Fuglsang et al, 2018 Granell et al, 2016 Meccariello et al, 2015 Wang et al, 2015	Case series Case Report Case Report Case Series Case report	1/16 1 1 2 1 total 6	Complete resection No recurrence at 1 -10 month follow up in all but additional lesion noted in one case 1 study no follow up	2 minor bleeding

4. Discussion

4.1 Types of robotic systems

Overwhelmingly the da Vinci® system has monopolised the market of robotic devices utilised in surgical society as a result of calculated marketing, clever patenting and successful lawsuits[7]. However, medical giants like Medtronic, Inc. (Minneapolis, MN, USA) and Johnson & Johnson, Inc. (New Brunswick, NJ, USA), in combination with Google LLC (Mountain View, CA, USA), continue to invest in new surgical robotic design and manufacturing. In addition, upcoming flexible systems such as i-Snake® (Imperial College London, London, UK) and Flex® systems (Medrobotics®, Raynham, MA, USA) promise to deliver even more than their predecessors[1, 8]. With competition comes compromise driving down costs and making this cutting edge technology more affordable and accessible. Exciting new research and future directions proposed include nano-surgery robots[9], autonomous systems and advances in augmented reality used in combination with current image guidance technology[10].

4.2 Advantages and disadvantages

Improved visualization with high magnification and widened field of vision are welcomed enhancements to the otolaryngology surgeon familiar with operating down a deep dark hole. Endoscopic surgery pioneering this benefit has limitations that robotic surgery has successfully overcome including the fulcrum effect[11], the physical limitations of operator/assistant stamina and anti-shake stabilized image technology[12]. In addition, as mentioned previously the upcoming flexible systems hope to improve vision and access even further. The use of multi-articulated instruments and 360 degree rotation allows for increased motion, dexterity and precision that the average human hand, wrist and shoulder cannot achieve[13]. Cosmetic outcomes in robotic surgery yield superior results through natural orifice access and allow smaller skin incisions at less visible sites[14, 15]. Robotic surgery can reduce time spent in the operating theatre and hospital stay in comparison to conventional open or endoscopic surgery[16]. In addition, limited dissection has been shown to improve functional outcome and expedite rehabilitation[17]. The ability of remote operating with telesurgery allows for sharing of resources and expertise easily between different centres and in difficult access locations such as war-torn countries, battlefields or even outer space. Robotic systems can also be utilised for training purposes with virtual skills simulations and preoperative planning exercises to avoid inexperienced surgeon patient contact[18].

The most limiting factor to widespread robotic surgery use currently remains cost. Huge upfront installation price followed by annual maintenance fees and costly disposable equipment, as well as requiring theatre space reserved solely for robot use and specialised staffing contribute to ever rising costs[19]. A common operator concern is the loss of haptic feedback and tactile feel limiting accuracy in identification of boundaries during resection or tension of retraction leading to tearing of tissues. However, many surgeons who advocate for robotic use report improved awareness of visual cues allowing for this loss of touch sensation. Current research and development is underway to create an artificial tactile sensation using vibrotactile technology[20]. Literature varies on time saving concerns with some papers reporting shorter operating times and earlier discharges[16] while others report increased overall theatre time due to inexperience and complicated equipment set up[21]. The lengthily training process, slow learning curve, limited access to robotic technology and lack of standardised formal training schemes are major obstacles in becoming a competent robotic operator.

Of course, the sparsity of good quality evidence and unproven benefits mean much additional research is required before a true consensus can be reached on risk, benefit and safety.

4.3 Location specific findings

Transoral robotic surgery in the oral cavity, oropharynx and upper aerodigestive tract are the areas in with most research is available. As noted in previous reviews of TORS for malignant cases, access remains a limiting factor. Several specialized adjuncts have been developed to improve visualisation including Crow–Davis, FK (Feyh-Kastenbaue), and Dingman retractors. The presence of retrognathia, micrognathia and trismus can be predictors of difficult access and assist in patient selection. Some centres advocate the importance of a separate preoperative endoscopy to ensure adequate exposure[22]. Whilst this is a common occurrence in the diagnostic workup of malignant disease, it may present a time and resource strain for benign conditions.

For percision work such as that needed in micro-laryngeal surgery refinements in robotic micro instruments may be required[23]. However, fine tremor hand movements are counteracted by the precision of a robotic arm[24].

The role of robotic surgery as an adjunct for management of difficult airways, tracheostomy and intubation was identified in this review[25, 26]. However, there is limited data available with small case series performed in optimal conditions. The time sensitive nature of airway management in contrast to the time consuming robotic setup would likely be a limiting factor.

One of the advantages of robot-assisted surgery for neck pathology is the ability to reposition the surgical access incision. Relocation of scars to less conspicuous sites, as in the trans-axillary or retro-auricular approach, eliminates unsightly scars. The advance of completely scarless surgery via a transoral approach is particularly appealing to those who value cosmetic results, have a propensity for keloid scaring, or cultural aversion to cervical scars[27]. A concern does arise with regards to the management of the emergency complication of the evolving hematoma. Without direct access to allow evacuation, early identification and expedited theatre response is vital.

The use of robot-assisted cochlear implant surgery is a very new and novel technique. Early studies suggest that robotic drilling is highly accurate. Despite the lack of direct visualisation, if used in combination with nerve monitoring and intraoperative image guidance a highly sensitive safe surgery is reported[28]. However, the labour intensive attention to detail and requirement of multiple disciplines to be involved results in prolonged operative time.

Endonasal uses for robotic assisted surgery are reported mostly as hybrid systems incorporating traditional endoscopic techniques and equipment. Previous attempts at non robotic systems to hold or stabilize endoscopes have been suboptimal with issues including rigid positioning, drifting, jerky movements and bulky obstructive placement[29]. The fusion of these techniques could provide a steady yet flexible image which is completely surgeon controlled, combining the advantages and limiting the disadvantages of both systems.

5. Conclusion

In conclusion there are multiple novel adaptations of robotic-assisted surgery being performed across the world in benign otolaryngology, head and neck pathologies. Exciting advances in technology and availability will expand this scope even further in the near future.

References

1. Garas, G. and A. Arora *Robotic Head and Neck Surgery: History, Technical Evolution and the Future.* ORL, 2018. **80**(3-4): p. 117-124.
2. Kwoh, Y.S., et al., *A robot with improved absolute positioning accuracy for CT guided stereotactic brain surgery*. IEEE Transactions on Biomedical Engineering, 1988. **35**(2): p. 153-160.
3. Lang, B.H., et al., *A systematic review and meta-analysis comparing outcomes between robotic-assisted thyroidectomy and non-robotic endoscopic thyroidectomy*. J Surg Res, 2014. **191**(2): p. 389-98.
4. Lang, B.H., et al., *A systematic review and meta-analysis evaluating completeness and outcomes of robotic thyroidectomy*. Laryngoscope, 2015. **125**(2): p. 509-18.
5. Miller, S.C., et al., *Transoral robotic base of tongue reduction for obstructive sleep apnea: A systematic review and meta-analysis.* Laryngoscope, 2017. **127**(1): p. 258-265.
6. Meccariello, G., et al., *Transoral robotic surgery for the management of obstructive sleep apnea: a systematic review and meta-analysis.* Eur Arch Otorhinolaryngol, 2017. **274**(2): p. 647-653.
7. Trehan, A. and T.J. Dunn, *The robotic surgery monopoly is a poor deal*. Bmj, 2013. **347**: p. f7470.
8. Mandapathil, M., et al., *Transoral surgery for oropharyngeal tumors using the Medrobotics(®) Flex(®) System - a case report.* International journal of surgery case reports, 2015. **10**: p. 173-175.
9. Song, B., et al., *Cellular-level surgery using nano robots.* J Lab Autom, 2012. **17**(6): p. 425-34.
10. Chan, J.Y.K., et al., *Augmented reality for image guidance in transoral robotic surgery.* J Robot Surg, 2020. **14**(4): p. 579-583.
11. Prasad, S.M., et al., *Prospective clinical trial of robotically assisted endoscopic coronary grafting with 1-year follow-up.* Ann Surg, 2001. **233**(6): p. 725-32.
12. Alessandrini, M., et al., *The AESOP robot system for video-assisted rigid endoscopic laryngosurgery*. Eur Arch Otorhinolaryngol, 2008. **265**(9): p. 1121-3.
13. Hillel, A.T., et al., *Applications of robotics for laryngeal surgery.* Otolaryngol Clin North Am, 2008. **41**(4): p. 781-91, vii.
14. Lee, C.R. and W.Y. Chung, *Robotic surgery for thyroid disease.* Minerva Chir, 2015. **70**(5): p. 331-9.
15. Shen, T., et al., *Performance of a Multifunctional Robot for Natural Orifice Transluminal Endoscopic Surgery*. Surg Innov, 2018. **25**(4): p. 364-373.
16. Mukhija, V.K., et al., *Transoral robotic assisted free flap reconstruction.* Otolaryngol Head Neck Surg, 2009. **140**(1): p. 124-5.
17. Burton, J., R. Wong, and T. Padhya, *Robotic-Assisted Surgery in the Head and Neck.* Cancer Control, 2015. **22**(3): p. 331-4.
18. Blavier, A., et al., *Comparison of learning curves and skill transfer between classical and robotic laparoscopy according to the viewing conditions: implications for training.* Am J Surg, 2007. **194**(1): p. 115-21.
19. Oliveira, C.M., et al., *Robotic surgery in otolaryngology and head and neck surgery: a review.* Minimally invasive surgery, 2012. **2012**: p. 286563-286563.

20. Abiri, A., et al., *Artificial palpation in robotic surgery using haptic feedback.* Surg Endosc, 2019. **33**(4): p. 1252-1259.
21. Rabinovics, N. and P. Aidan, *Robotic transaxillary thyroid surgery*. Gland Surg, 2015. **4**(5): p. 397-402.
22. Weinstein, G.S., et al., *Transoral robotic surgery: does the ends justify the means?* Curr Opin Otolaryngol Head Neck Surg, 2009. **17**(2): p. 126-31.
23. Remacle, M. and V.M.N. Prasad, *Preliminary experience in transoral laryngeal surgery with a flexible robotic system for benign lesions of the vocal folds.* Eur Arch Otorhinolaryngol, 2018. **275**(3): p. 761-765.
24. Patel, K.B., et al., *Transoral robotic excision of laryngocele: Surgical considerations.* Head Neck, 2019. **41**(4): p. 1140-1143.
25. Hemmerling, T.M., et al., *First robotic tracheal intubations in humans using the Kepler intubation system.* Br J Anaesth, 2012. **108**(6): p. 1011-6.
26. Montevecchi, F., et al., *Transoral robotic surgery (TORS): a new tool for high risk tracheostomy decannulation.* Acta Otorhinolaryngol Ital, 2017. **37**(1): p. 46-50.
27. Boyce, B.J., et al., *Transoral robotic approach to parapharyngeal space tumors: Case series and technical limitations.* Laryngoscope, 2016. **126**(8): p. 1776-82.
28. Caversaccio, M., et al., *Robotic middle ear access for cochlear implantation: First in man.* PLoS One, 2019. **14**(8): p. e0220543.
29. Bolzoni Villaret, A., et al., *Robotic Transnasal Endoscopic Skull Base Surgery: Systematic Review of the Literature and Report of a Novel Prototype for a Hybrid System (Brescia Endoscope Assistant Robotic Holder).* World Neurosurg, 2017. **105**: p. 875-883.

