Transoral minimally invasive robotic surgery for carcinoma of the pharynx and the larynx: a new approach

Philippe Céruse[a], Benjamin Lallemant[b], Sylvain Morinière[c], Sébastien Vergez[d], Adil Benlyazid[e], Antoine Ramade[a], Guillaume Buiret[a] and Yann Mallet[f]

Partial laryngectomy is an old but well-accepted surgical treatment for selected carcinomas of the larynx. Actually, the transcervical approach remains the most popular even if the transoral laser approach is useful in some cases. Transoral robotic surgery is a new promising surgical procedure in head and neck oncology as an alternative to conventional surgery with decreased morbidity. The aim of this study is a description of the state of the art by a review of the literature. We emphasize limits and future prospects on this topic with a special focus on dependability. *Anti-Cancer Drugs* 22:591–595 © 2011 Wolters Kluwer Health | Lippincott Williams & Wilkins.

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[a]Centre Hospitalo-Universitaire Lyon-Sud, Lyon, [b]Centre Hospitalo-Universitaire de Nîmes, [c]Centre Hospitalo-Universitaire Bretonneaux, Tours, [d]Centre Hospitalo-Universitaire de Rangueil-Larey, [e]Centre Anticancéreux Claudius Regaud, Toulouse and [f]Centre Anticancéreux Oscar Lambret, Lille, France

Correspondence to Dr Philippe Céruse, MD, PhD, Centre Hospitalier Lyon-Sud, Chemin du Grand Revoyer, Pierre Bénite 69395, France
Tel: +33 478861691; fax: +33 478863336;
e-mail: philippe.ceruse@chu-lyon.fr

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Introduction

Despite its small size, the larynx is of major importance because of its vital, functional, and relational functions such as breathing, eating, and speaking. In the history of surgery it has probably given rise to the greatest number of descriptions of surgical techniques for tumor resection, whether functional or not. These surgeries were the gold-standard treatments of laryngeal malignancies for many years, and from time immemorial surgeons have endeavored to preserve laryngeal functions. At the beginning of the 19th century, laryngeal tumor removals were attempted by laryngofissure (Desault 1801, Bowes 1833) without success. The term 'partial laryngectomy' was proposed during this period by Sands (1865) for this type of intervention. Solis-Cohen seems to be the first to successfully perform a transcervical partial laryngectomy for a vocal cord tumor in 1867 [1]. Billroth described the first total laryngectomy to treat cancer patients in 1873. Since then, many transcervical surgical procedures have been described to remove laryngeal tumors while preserving laryngeal functions. Only the best known are cited here: Huet for the hyo-thyro-epiglottectomy in 1938; Alonso for the horizontal laryngectomy in 1939; Leroux-Robert for the frontolateral laryngectomy in 1948 and supra-glottic laryngectomy in 1956; Andre and Laccourreye for the hemipharyngo laryngectomy in 1962; and Majer and Piquet in 1972 for subtotal reconstructive laryngectomy with cricopexy, also known as supracricoid laryngectomy in the English-language literature [2]. Transoral surgery was very soon explored. In 1886, Fraenkel transorally treated a tumor of the vocal cords using a mirror, but it was necessary to wait for the development of direct laryngoscopy to simplify such interventions. Lynch seems to be the first author to report a large series of laryngeal tumors transorally treated with direct laryngoscopy [3]. At the beginning of 1960s, the surgical microscope and then micro instruments adapted to transoral surgery improved the outcome of this surgery, which remained, however, indicated for small tumors. In 1970, the CO_2 laser coupled with the microscope enabled the development of transoral surgery for more advanced laryngeal tumors, thanks to pioneers such as Jako [4], Strong and Jako [5], Vaughan [6], Vaughan *et al.* [7], Eckel and Thumfart [8], Steiner [9], and Eckel [10].

Transoral surgery with laser

Advantages

Partial laryngeal surgery exposes patients to swallowing disorders. During the pharyngeal swallowing phase, aspirations are physiologically prevented by glottis closure, and the ascension of the larynx and its covering by the epiglottis by placing it under the base of the tongue. These movements are reflexes activated particularly by the superior laryngeal nerve, which is responsible for the sensitivity of the larynx [11]. During partial laryngectomy, whether transcervical or transoral, parts of these structures are destroyed. The importance of aspiration is directly related to the location and size of the resection of the tumor and anatomical structures. Resection of the glottis only will give little or no aspiration. Resection of the epiglottis alone will give less aspiration than if a part of the base of the tongue is resected at the same time [12–16]. For an equivalent size of resection, aspirations are less frequent after transoral surgery than after transcervical surgery. Indeed, transoral

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surgery preserves important structures involved in the mechanisms of swallowing: the infrahyoid and constrictors of the pharynx muscles, the hyoid bone, the thyroid cartilage, and the superior laryngeal nerves [17]. Moreover, unlike transcervical laryngectomy, in which temporary tracheotomy is systematic, the percentage of tracheotomies performed with transoral laryngectomies varies from 0 to 32% [18]. The absence of tracheotomy is an additional factor for a fast recovery of normal swallowing, as the tracheotomy tube restricts the ascending movements of the larynx during swallowing.

The limitation of aspirations after transoral laryngectomy decreases *de facto* the risk of Mendelson's syndrome [19]. However, some studies showed equivalent rates of Mendelson's syndrome for the two techniques. This could be explained by the greater number of elderly patients in transoral laryngectomy groups, as age is an unfavorable factor in postoperative swallowing disorders [20,21].

These good functional performances reduced the length of hospitalization in patients, and the cost of this technique was generally less than that of transcervical approaches and even radiotherapy for small tumors [22,23]. It is also important to note that the oncological results obtained with transoral surgery were equivalent to those obtained with transcervical surgery [21,24,25].

Limits

This surgery has limits imposed by the technology of the instruments. First, the laser beam is perfectly effective only if it is perpendicular to the treated zone. It is best for tumors of the glottis and the vestibule of the larynx, whereas it is more difficult and even impossible for hypopharyngeal locations. Moreover, laryngeal microsurgery instruments are not multidirectional. The tumor therefore needs to be perfectly 'exposable', which is not always the case despite the use of several sets of laryngoscopes adapted to this procedure and the frequent changes of position during the procedure. The operator needs both hands to perform this surgery, one hand controlling the micromanipulator of the laser and the other hand to maintain the position, to direct the tumor, to aspire, etc. For these reasons, transoral surgery with the laser is simple and fast for small tumors of the glottis or the vestibule of the larynx, but seems complex and time-consuming for supraglottis or hypopharyngeal tumors, causing, in the majority of cases and in contradiction with the rules of the oncological surgery, piecemeal resection of the tumor.

Transoral robot-assisted surgery

First steps

The recent arrival of the da Vinci robot (Intuitive Surgical, Sunnyvale, California, USA) in the arsenal of surgical tools has allowed a new approach in minimally invasive laryngeal and pharyngeal surgery. This telerobotic system is the product of the integration of the most recent advances in terms of telemanipulation, the miniaturization of robotic mechanical components, and three-dimensional vision optics. The robot itself has four articulated arms: three instrument-carrier arms and one central optic-carrier arm. The instruments are remarkable by their small size (5 mm in diameter), and the fact that they can be oriented in all three spatial dimensions to almost 360°. They are operated by the surgeon from the surgical console, which has a three-dimensional imaging system and two arms. This new instrument, initially developed for abdominal and thoracic surgery, seemed from the beginning very promising in endoscopic ear, nose, and throat (ENT) surgery. It provides transoral access to the pharyngolarynx with all the surgical instrumentation necessary for tumoral resection, and improves the precision of the surgical gesture while immersing the surgeon in the operative field in a virtual manner. The limits of transoral laser surgery are thus pushed back.

The setting up of this new tool involved several steps

The first step was to develop a simple safe procedure to insert instruments into the narrow tunnel corresponding to the oral cavity, the pharynx and the larynx. The clinical work by Hockstein *et al.* [26,27] made it possible to overcome this difficulty. The use of a retractor such as the FK Retractor (Gyrus Medical GMPH; Gyrus Medical Inc., Maple Grove, Minnesota, USA) rather than a traditional laryngoscope provides better exposure in robotized surgery.

The second step was to evaluate the use of the robot in terms of safety. The same author produced two experimental studies. The first evaluated the quality of hemostasis in endoscopic robotic surgery carried out on a canine model: control of hemostasis of the lingual artery or the small arteries and veins of this area [28]; and the second carried out on human cadavers evaluated the potential damage caused by this robot. Forcing the instruments generated only superficial wounds of the skin or mucosa, and all attempts to damage teeth or to cause mandible or spinal column fractures failed [29].

The last step evaluated the surgical quality of the resection. Feasibility studies on human and canine models in transoral robot-assisted surgery (TORS) of the base of the tongue showed excellent visualization of the area and great maneuverability of the instruments with a quality of resection considered satisfactory [30]. These conclusions were corroborated by experimental studies by the same authors about the feasibility of larynx and pharyngolarynx resection [27,31,32]. The foundations of TORS were established and interventions in patients could be conducted. In 2005, McLeod and Melder [33] published the first successful resection of a supraglottic benign cyst. In 2007, O'Malley *et al.* [30] published the first resection of a carcinoma of the base of

the tongue by TORS with healthy margins in the final histology and straightforward follow-up with no repercussions on the voice or swallowing one month after the intervention. One year later, the same authors reported three other cases of patients operated upon for supraglottic cancer with healthy histological margins, with no complications or major blood loss and procedure durations that were comparable with or even shorter than in transcervical or transoral surgery with the laser [34].

First experiments and teaching

The first surgical series were very recent and remained limited, but their results widened the horizons for the interest of this technique and also showed its limits.

Feasibility

One of the major purposes of TORS is to predict before surgery whether the anatomical conditions would allow good enough tumor exposure to carry out an optimal resection. Weinstein *et al.* [35] in a series of 27 patients operated upon by TORS for tonsil squamous cell carcinoma proposed a systematic preoperative endoscopy to select suitable patients. The principal criteria of exclusion were related to the anatomical situation of the lesion and its size, the quality of the mouth opening, the patient's teeth, and his maxillomandibular morphology. In a more recent series of 20 patients with malignant head and neck carcinoma eligible for a TORS procedure, 18 benefited from the procedure with resection of T1/T2 tumors of the tonsil, the tongue, and the posterior or supra-glottic pharyngeal wall, while in two patients the tumor was inexposable. Moreover, in this study, the per-patient time to set up the apparatus followed a quickly decreasing curve with a mean duration of approximately 30 min from the sixth case onwards [36]. Boudreaux *et al.* [37], in their series of 36 patients with squamous cell carcinoma of the head and neck, showed that the predictive factors of TORS failure were tumor size ($P = 0.01$) and patients' teeth ($P = 0.07$); initial selection during a preoperative endoscopy was not specified. In conclusion, if a simple preoperative evaluation is made, this technique is highly feasible, but it is necessary to warn the patient about the possible preoperative need to return to a transcervical approach.

Oncological results

As this procedure has been available for a very short time, it is not possible to evaluate the long-term oncological results. However, the histological margins of resection are a good indicator of the reliability of a surgical technique. In the principal publications, the margins were negative in 96–100% of cases [35–37]. Despite the small series of patients, these results are very encouraging, but need to be confirmed by complementary studies and long-term results.

Functional results

The aim of minimally invasive surgery is to offer better functional results than those obtained with transcervical surgery while preserving equivalent carcinological results. Transoral surgery with the laser showed that it was possible to combine a good performance in both functional and carcinological outcomes in some well-selected tumors of the upper aerodigestive tract (UADT). TORS should, in theory, obtain identical results. The speed of swallowing recovery is the most important factor to take into account in the functional results. In the series by Genden *et al.* [36] none of the patients operated upon using TORS required a nasogastric tube, thanks to intensified swallowing rehabilitation (18 patients, T1, T2 of the UADT). In the study by Boudreaux *et al.* [37], 13 patients out of 29 required a nasogastric tube at the end of their very short hospitalization (median: 2.9 days; range: 1–13 days). The factors associated with the nasogastric tube were age ($P = 0.02$), laryngeal location ($P < 0.001$), and the size of the tumor ($P = 0.02$).

Tracheotomy is also an important factor for functional continuation and postoperative quality of life. TORS did not require tracheotomy in the majority of the patients. Only one patient required a nonprogrammed tracheotomy in the Weinstein *et al.* [35] series of 27 cases of enlarged amygdalectomy, and none for the 18 patients in the Genden *et al.* [36] series. Seven patients required prolonged intubation (48 h) and one patient required a tracheotomy in a series of 29 patients in the series of Boudreaux *et al.* [37]. These positive data, however, need to be confirmed by other studies.

Complications

To date, only minor complications related to the procedure have been reported. In the series of 63 patients treated with TORS by the team of the University Hospital of Pennsylvania (Philadelphia) for a large range of benign and malignant pharyngolaryngeal tumors, duration, blood loss, and morbidity were comparable with those in transcervical or transoral laser surgery [38]. In the majority of TORS procedures, blood loss was very low (< 200 ml) [36]. Five patients out of 27 (19%) operated upon for tonsil cancer developed a minor complication with no significant side effects. One case of late bleeding requiring hemostasis in the operating room was reported [35]. Other studies with comparable results have been reported, with no cases of death, pneumonia, or fistula.

Limits and future

Limits

Many questions remain unanswered and will undoubtedly be a subject of research in the future.

The da Vinci robot was initially designed for abdominal and thoracic coelioscopic surgery, but has since been used by ENT surgeons for transoral surgery. Improvements have been made as a result of the development of new

optics and smaller diameter instruments. However, certain lesions still remain inaccessible to this technique, and adaptation of the instruments will enable wider indications for TORS in ENT. Moreover, in certain locations, in-depth tumoral infiltration requires palpation to control the quality of the resection in the absence of a visual reference mark. This palpation is not possible in TORS in the absence of sensory-feedback from the instruments. Currently, the resection of infiltrating lesions remains very difficult, even impossible, using this technique.

The fast development of this new tool (more than a thousand hospitals equipped throughout the world), the growing number of interventions carried out globally (more than 60% of all prostatectomies carried out in the USA are TORS procedures), and the initial costs of approximately 2 million USD associated with 100 000 USD of annual maintenance and 200 USD per intervention raise the question of the financial burden of such tools in our economic context. At present, only incomplete answers are available. Thus, it seems essential to answer the following question: are the clinical benefits real compared with traditional procedures, and what is its cost?

Future

This new tool seems very promising for transoral surgery. New fields of investigation in oncological surgery of the UADT will probably be explored in particular, thanks to the possibility of combining laser, which is now routine in ENT endoscopic procedures, with the robot or by coupling the robot with a navigation system in particular for the ablation of more infiltrating tumors [39]. Preclinical studies have also evaluated the feasibility of vascular microanastomosis using the da Vinci robotic system for free flaps, which are very widely used in reconstructive surgery of the head and neck [40,41]. This instrument has also been used successfully in thyroid surgery through a hidden axillary scar rather than the traditional cervical scar. It is also possible to perform cervical neck dissection using TORS [42,43]. Skull base surgery has also been experimented with in combination with TORS, and has enabled less invasive incisions than the complex incisions used until now [44,45].

Conclusion

The development of telerobotic surgery of UADT tumors is undoubtedly a major advance in the development of ENT surgery. Its intrinsic qualities, unequalled precision of the gesture, the freedom of movement, and hitherto unknown surgical instruments give hope for significant improvements in the surgical management of UADT cancers with fewer functional sequelae and reduced preoperative and postoperative morbidity and mortality. Miniaturization and sensory feedback from the instruments, coupled with improved endoscopic systems (flexible optics, navigation systems incorporated into the robot, etc), will probably make this new system very popular. The first studies indicate real progress in the management of tumors that were until now inaccessible using the transoral approach. Expected benefits for the patient include faster and easier functional rehabilitation.

It is, however, necessary to evaluate the medical benefit of this tool, which was very recently installed in our hospitals and clinics. In France, in ENT, a national observatory coordinated by the French Groupe d'Etudes des Tumeurs de la Tête Et du Cou has been set up. It will systematically record the outcomes in patients operated upon using the technique to evaluate its reliability and benefits so that patients, as well as the public and private care organizations, will benefit as much as possible from this progress. To make this technique available to as many patients as possible, the quality of the studies to come in this field will be critical.

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