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MINIMALLY INVASIVE TOTAL LARYNGECTOMY: A REVIEW OF NEW ROBOTIC SURGICAL TECHNIQUES

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Abstract: Background and objective. Advances in organ preservation have reduced the need for total laryngectomies in advanced laryngeal cancer. Minimally invasive surgical techniques, such as transoral laryngectomy with the da Vinci robot, are available, but clinical evidence is limited and cost is high. This study will compare robotic transoral total laryngectomy with open "narrow-field" surgery, analyzing advantages, disadvantages and the technologies used in each approach. **Materials and methods**. We will compare four minimally invasive laryngectomy (MISL) techniques: LTCE, robotic LT-TO (TORS), ultrasonic LT-TO (TOUSS) and laser microsurgery LT-TO. We will discuss six key surgical steps: incision and exposure, prelaryngeal muscle section, laryngeal dissection, pharyngotomies, ligation of the laryngeal pedicle and reconstruction of the neopharynx. Finally, we will critically evaluate the advantages and disadvantages of each technique. **Results**. The four laryngectomy techniques share some surgical steps, such as: Incision, tracheotomy and exposure of the larynx with section of the prelaryngeal muscles: This is a transcervical step in all techniques, except in LT-TO (transoral techniques), in which a prelaryngeal endoscopic tunnel is created. 2. Posterior perilaryngeal dissection and section of the constrictors: It is transcervical in all of them, but in LT-TO a second endoscopic tunnel is performed. 4. Pharyngotomies and dissection of the pre-epiglottic space: The pharyngotomy lines are the same in all, but in the LT-TO they are done under direct vision from the mouth. 5. Ligation of the superior laryngeal pedicle: It is mandatory in all, but the location varies according to the approach (transcervical or transoral). 6. Reconstruction and suture of the neopharynx: Similar in all, with the possibility of suturing from the mouth in the LT--TO. **Conclusions**. LT-TO, with or without a robotic platform, is considered a highly sophisticated technological evolution of LTCE. The transoral techniques use different technologies, but follow similar principles. The surgical specimens removed in both approaches are very similar. Therefore, we argue that the indications for LT-TO should match those for LTCE: fragile patients with dysfunctional larynxes or salvage laryngectomies.

Keywords: Narrow-field total laryngectomy; Transoral total laryngectomy; Transoral robotic surgery.

Abbreviations. LTCE: narrow-field total laryngectomy; LT-TO: transoral total laryngectomy; WNTL: Wide-narrow total laryngectomy; TOTL: transoral total laryngectomy. MCL: laser microsurgery

INTRODUCTION

Advances in organ preservation have changed the therapeutic schemes for the treatment of advanced stages of laryngeal cancer, significantly reducing the need for total laryngectomies. Currently, total laryngectomy is reserved for cases in which non-surgical treatments have proven ineffective. Rescue" total laryngectomy involves intervention on tissues previously exposed to the toxicities of chemoradiotherapy, which complicates the healing process and increases the incidence of complications, especially the appearance of post-laryngectomy fistulas.

Approximately one hundred years ago, American surgeons (1-4) began employing a minimally invasive approach to total laryngeal removal in selected patients. In this context, they preserved the prelaryngeal muscles in fragile individuals without cartilage invasion or lymph node metastases. Current technologies offer ample potential for the development of minimally invasive techniques in various areas of surgery. In 2013, Lawson (5) demonstrated the feasibility of total laryngectomy via a transoral approach assisted by the da Vinci robot. Other surgeons have succeeded in performing transoral total laryngectomies

without the use of robotic platforms, using ultrasonic technology (6) and, more recently, by transoral laser microsurgery (7).

Despite these advances, global clinical evidence on the transoral approach remains limited at present. It is estimated that the use of the surgical robot doubles the costs of total laryngectomy compared to open surgery (9), although laser and ultrasound remain cost competitive with open surgery.

In this comparative study we propose to compare the LT-TO surgical technique with its equivalent in open transcervical surgery, the LTCE. Our objective is to identify which specific steps of the transoral approach make this technique less aggressive than LTCE, and to make a critical analysis of the advantages and disadvantages of the transcervical versus transoral approach. Within the transoral approaches, we will also compare the different technologies between the different technological platforms available.

MATERIAL AND METHODS

We will compare the four currently available LTMI techniques, starting from the original description of each technique in the literature:

1. LTCE (4,10)
2. Lawson LT-TO robotics (TORS) (5)
3. Ultrasonic LT-TO (TOUSS) by Fernandez-Fernandez (6)
4. LT-TO by Amhadi laser microsurgery (ML) (7)

We have established six fundamental surgical steps, which we will compare according to each technique:

1. Incision, tracheotomy and exposure of the larynx
2. Section of the prelaryngeal muscles
3. Posterior laryngeal dissection and section of the constrictors
4. Pharyngotomies and pre-epiglottic space dissection
5. Ligation of the superior laryngeal pedicle
6. Reconstruction of the neopharynx

Within the transoral techniques, we establish for each surgical step the type of surgical approach with which it is performed according to the technique:

1. Classic transcervical approach
2. Transcervical endoscopic approach
3. Transcervical approach.

Finally, we will make a critical evaluation of the advantages and disadvantages of each.

RESULTS

COMPARISON OF ABORTIONS AND TECHNIQUES

INCISION, TRACHEOTOMY AND EXPOSURE OF THE LARYNGEAL (FIG.1)

In any of the four techniques, this is a transcervical time, although with a specific maneuver in the LT-TO. The incision and tracheotomy with ligation of the thyroid isthmus is identical in the four techniques. Exposure of the prelaryngeal muscles of the LT-TO is performed by a specific and different maneuver. As opposed to the conventional dermoplatismal flap lift of the LTCE, the LT-TO, regardless of the technology used, dissects an endoscopic prelaryngeal tunnel from the tracheotomy incision. To do so, it sections the sternohyoid muscle at the level of the tracheotomy and dissects a surgical plane with the endoscope deep to the stenohyoid and superficial to the sternothyroid and thyrohyoid, in the direction of the hyoid. This space is called the anterior prelaryngeal endoscopic tunnel.

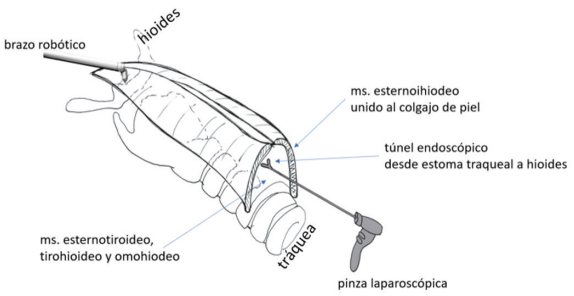


Figure 1.

SECTION OF THE PRELARYNGEAL MUSCLES

The sections of the prelaryngeal muscles are performed by transcervical approach in all four techniques. The difference lies in the fact that in LT-TO, regardless of its technology, they are performed by endoscopic transcervical approach, from the dissected prelaryngeal tunnel. The sections are somewhat different according to the technique (***Figure 2***):

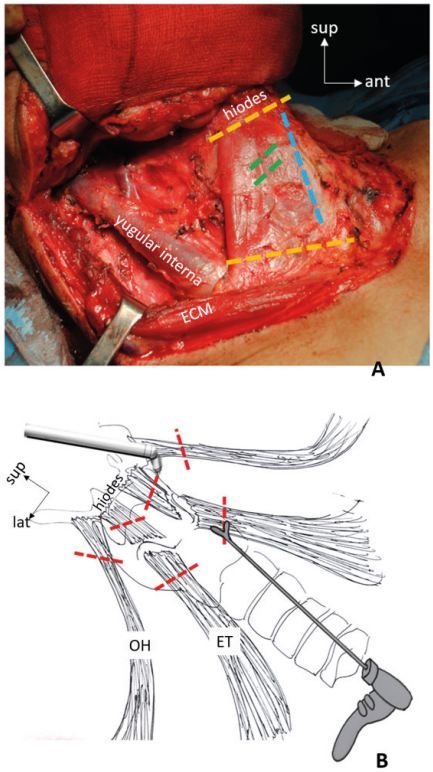


Figure 2 A and B

a) In transcervical **LTCE** (Fig.2A), we vertically incise the prelaryngeal muscles near the thyroid keel, including the external perichondrium. We dissected by subperichondrial plane the thyroid wings from the thyroid keel toward the posterior edge of the wings, from medial to lateral, preserving the prelaryngeal muscles for the final reinforcement of the neopharyngeal suture.

b) in the **LT-TO** (*Fig.2B*), from the endoscopic tunnel we section the hyoid insertion of the sternohyoid and omohyoid muscles and the laryngeal insertions of the *thyrohyoid* and *sternothyroid* muscles. Thus, the sternohyoid, although sectioned at its proximal and distal insertions, remains in continuity with the platysma and skin throughout the procedure. If a robot is available, the muscle section can be performed from the mouth, after the pharyngectomy by vallecula.

POSTERIOR PERILARYNGEAL DISSECTION AND SECTION OF THE CONSTRICTORS

It is also performed by transcervical approach, although in the LT-TO it is performed by endoscopic cervical approach, dissecting a second tunnel through the posterior aspect of the larynx, between the larynx and the esophagus towards the arytenoids. The section of the constrictors is performed in the same area in all techniques: vertically, at the posterior border of the thyroid cartilage, up to the upper horn of the thyroid ala. If the robot is available, the sections of the constrictors can be made from top to bottom through the transvallecular pharyngotomy.

PHARYNGOTOMY AND DISSECTION OF THE PRE-EPIGLOTIC SPACE (FIG.3 AND 4)

The pharyngeal mucosal incision line is the same in all approaches, transcervical and transoral: superior pharyngotomy through the vallecula, lateral pharyngotomy through the pyriform sinuses and posterior or inferior pharyngotomy through the retroarytenoid mucosa. This is the true transoral time of the LT-TO.

a) In transcervical **LTCE**, pharyngotomies are performed from the neck, after section of the hyoid insertion of the supra-hyoid muscles and dissection of the pre-epiglottic space from the hyoid towards the vallecula. The first pharyngotomy can be done via the vallecula, laterally via a pyriform sinus or retrocricoid, but the surgeon always "opens the pharynx" in his first "blind" stroke. He then has a direct view of the larynx to perform the other pharyngotomies.

b) **LT-TOs,** regardless of their technological platform, perform all pharyngotomies under direct vision from the mouth. The technology used does not change the technique: the lire border of the epiglottis is tractioned towards the arytenoids to expose the vallecula well, and the mucosa of the vallecula is incised with the 5 mm monopolar spatula of the robot (TORS), with the laser spot (MCL) or with the long monopolar needle (TOUSS). The incision is continued through the aryepiglottic fold and through the retrocricoid mucosa.

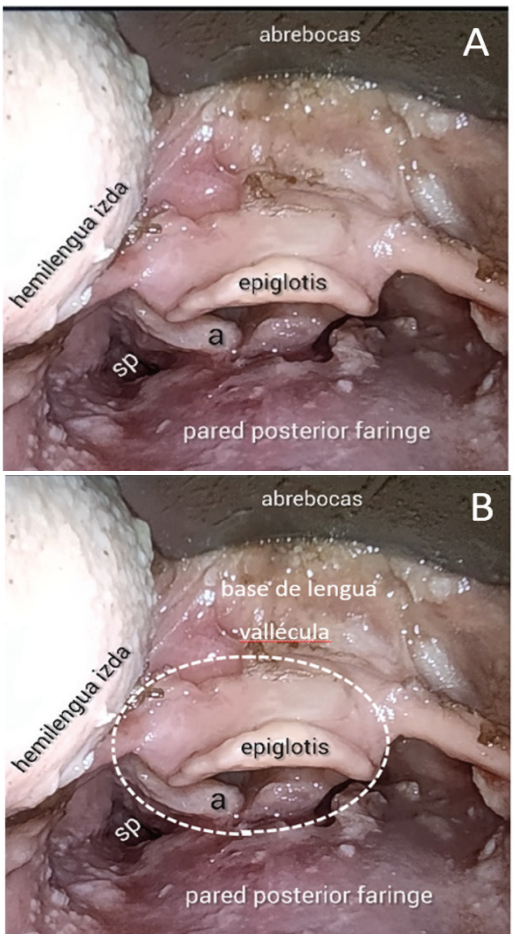
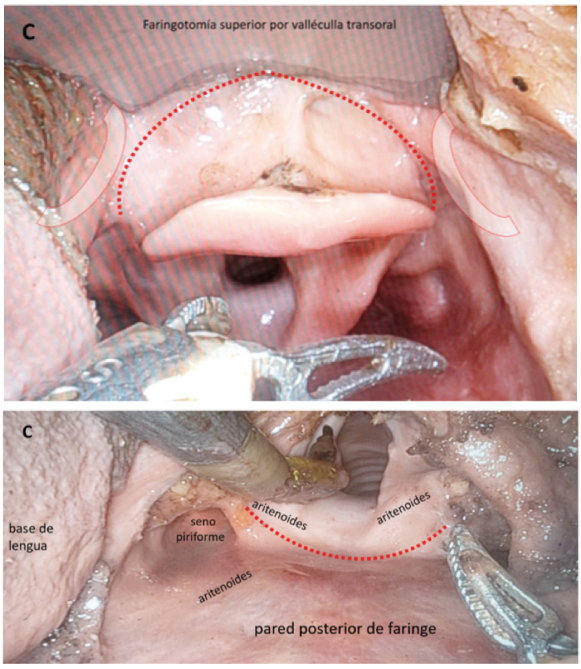


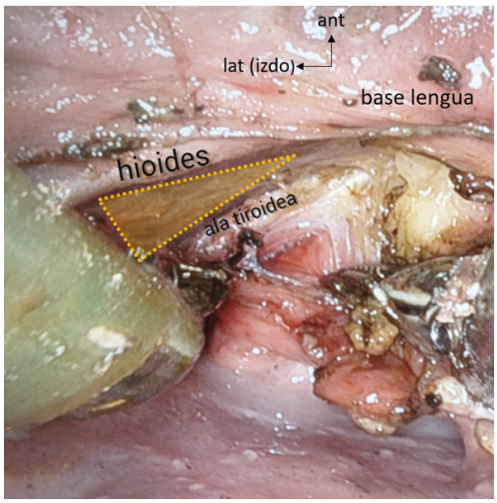
Figure 4.

Authors' note: the images of transoral surgery of the larynx were taken during the development of the XI theoretical-practical course of initiation to robotics in head and neck surgery with permission of Drs. Granell and Gutierrez-Fonseca. https://ifmec.com/es/producto/11acurso-teorico-practico-de-iniciacion-alarobotica-en-cirugia-decabeza-ycuello/. The authors thank them for their teaching and dissemination of laryngeal robotic surgery.

In the three transoral techniques, dissection is continued over the roof of the preepiglottic space up to the posterior aspect of the body of the hyoid. The thyrohyohyoid ligament is sectioned below the inferior border of the hyoid and the dissection is joined with the anterior perilaryngeal tunnel that we had dissected by transcervical approach.



- In the transoral approach, after sectioning the vallecula and dissecting down to the body of the hyoid, the anatomical landmark of the greater horn of the hyoid is sought. The superior laryngeal pedicle is ligated with vascular clips after the artery has pierced the thyrohyoid membrane (Fig.5).



LIGATION OF THE SUPERIOR LARINGEOUS PEDICLE (FIG.5)

Pedicle ligation is a mandatory surgical step in total laryngeal surgery, regardless of the approach, technology or technique used. In the transoral approach it is a transoral time, like pharyngotomies. The area where the pedicle should be ligated varies according to the approach selected:

- In the classic transcervical approach, the pedicle is ligated on the surface of the thyrohyoid membrane before perforating it.

RECONSTRUCTION AND SUTURE OF THE NEOPHARYNX

After removal of the larynx, pharyngeal reconstruction is very similar in the four techniques: direct suture of the mucosa, the submucosal line and prelaryngeal muscle reinforcement. If possible, the suture should be horizontal. In transoral techniques (3, 12-14), suturing can be performed from the mouth, but some surgeons prefer from the anterior perilaryngeal tunnel. The tracheostoma is sutured to the skin all the way around without any difference between transoral or transcervical techniques and a phonatory prosthesis can be placed if indicated.

INSTRUMENTAL USADO EN CADA TECNICA DE LT-TO

	Endoscopio	Microscopio	Retractor/Laringoscopio	Instrumental específico (consumibles)
LT-TORS	si	no	WO-FK o Remacle LARS	Disector Maryland y espatula monopolar de 5 mm
LT-TOUSS	si	no	WO-FK	Thunderbeat™ de 35 cm y aguja monopolar larga
LT-MCL	si	si	K Strorz 8588N	No

Table 1 summarizes the instruments used in each transoral technique.

PASOS QUIRURGICOS	LTCE	LT-TO
1. Incisión, traqueotomía y exposición de la laringe	transcervical (colgajo dermoplatismal)	***transcervical endoscópico***
2. Sección de los músculos prelaríngeos	transcervical	***transcervical endoscópico***
3. Disección laríngea posterior y sección de los constrictores	transcervical	***transcervical endoscópico***
4. Faringotomías y disección del espacio pre-epiglótico	transcervical	***TRANSORAL***
5. Ligadura del pedículo laríngeo superior	transcervical	***TRANSORA*** L
6. Reconstrucción de la neofaringe	transcervical	***TRANSORAL*** o trancervical

Table 2 shows the different approaches for each surgical step for LTCE and LT-TO.

VENTAJAS de la CIRUGIA TRANSORAL frente a la LTCE

1. La vista directa permite preservar al máximo la mucosa, y disminuir el tamaño del defecto faríngeo
2. Evita crear planos quirúrgicos entre la carótida y la laringe, importante sobre todo en laringuectomías totales "de rescate"
3. La preservación del músculo esternohioideo sin despegamiento del colgajo dermoplatismal
4. Se preserva la irrigación y la sensibilidad a la faringe y a la musculatura prelaríngea

VENTAJAS ESPECIFICAS DE CADA TECNOLOGÍA EN LA CIRUGIA TRANSORAL

TORS-LAWSON

1. La visión 3D inmersiva supera la calidad de visión del ojo humano, de las ópticas 3D y del microscopio quirúrgico
2. La reducción de la estancia estancia hospitalaria ya ha sido demostrada en la LSG-TORS [cita].

LT-TOUSS

1. Evita adquirir equipos costosos como el robot quirúrgico y el láser y su mantenimiento
2. El costo de los consumibles (Thunderbeat™ de 35 cm y electrodo largo de aguja monopolar) es razonable

LT-MCL

1. Es latécnica transoral laríngea minimamente invasiva que cuenta con más experiencia desde su desarrollo clínico por Steiner et al. en 1988 [1cita].
2. El equipo de láser es menos costosos que el robot quirúrgico, reduciendo el costo de la LT-TO a la mitad
3. El equipo no necesita consumibles
4. El equipo, en general, no se comparte con otras especialidades

DESVENTAJAS ESPECIFICAS DE CADA TECNOLOGÍA EN LA CIRUGIA TRANSORAL

TORS-LAWSON

1. Coste de adquisición del equipo y mantenimiento
2. Capacidad de formación del cirujano y su equipo
3. Tiempo de ocupacion del quirófano, que se comparte con otras especialidades

LT-TOUSS

1. Curva de aprendizaje larga

LT-MCL

1. Coste del equipo y mantenimiento
2. Curva de aprendizaje

Table 3 shows the advantages and disadvantages of each approach and, within the transoral approach, of each available technology.

DISCUSSION

The LTCE technique, although it preserves the laryngeal muscles and avoids dissections between the larynx and carotid artery, requires a dermoplatysmatic flap lifting. LT-TO, based on the development of sophisticated surgical technology (robot, laser, ultrasonic scalpel...) aims, since Lawson's description in 2013 (5), to further limit the exposure of deep cervical structures and to enhance smaller pharyngostomies with direct vision from the mouth. As we have seen, technically none of the described LT-TOs are pure transoral procedures, but "hybrid" procedures, even if a surgical robot is available. All of them have a first cervical time through the tracheotomy incision and then a transoral endoscopic approach to the pharyngolaryngeal mucosa. What makes the cervical time of the LT-TO minimally invasive is that no dermoplatysmal flap is raised, but the cervical time is performed through an endoscopic tunnel dissected between the planes of the prelaryngeal muscles. This approach means that there are no incisions in the neck, but also, by preserving the strerohyoid muscle in continuity with the platysma, it provides muscle reinforcement on the neopharyngeal

suture of high quality tissue, which according to some surgeons could even avoid the need to place local myofascial or micro-anastomosed flaps on the neopharyngeal suture. Moreover, performing pharyngotomies with excellent direct vision with a microscope, high-quality optics or an immersive 3D console certainly outperforms the human eye, which in LTCE performs the first pharyngotomy outside the pharynx. For all these reasons, LT-TO is technically less invasive than LTCE, as it preserves the blood and neurological supply to the pharynx and surrounding musculature, requires fewer incisions that avoid scarring and subsequent fibrosis, and offers better quality neopharyngeal recostruction. Achieving a less invasive total laryngectomy is desirable in any patient, but especially in very fragile patients in whom chemotherapy is contraindicated or in salvage total laryngectomies in previously chemoradiated patients.

LT-TO has a major limitation with all available technological platforms: there are patients in whom the larynx cannot be adequately exposed for a transoral approach. Specific devices for this surgery are still being developed to improve transoral exposure. Robotic LT-TO has another important limitation: the high cost of the surgical robot, its maintenance and consumables. Dombee's group (9) has estimated the average cost of an open total laryngectomy at 3,350 euros, similar to the cost of performing the technique with laser microscopy, being almost double the cost with the surgical robot (5,650 euros).

Total laryngectomy with MCL (7) and TOUSS (6) do not require expensive robotic systems. Microscopic laser surgery has been the standard of conservative laryngeal surgery for decades. But the surgical movements over the larynx that we can perform with laser or laparoscopic forceps are more limited than those performed by the robot. The laser works only in the perpendicular line, although with a traction forceps we can present the tissues to work in another angle. The TOUSS instruments, 35 cm long, similar to those of laparoscopy, only allow movements with four degrees of freedom: down-up, right-left, in-out and rotation. The robotic instruments allow 7 degrees of freedom, extendable with the surgical arms. The surgical gesture of suturing the neopharynx with a surgical robot has a much shorter learning curve than the long learning curve of any laparoscopic technique that we adapt to the pre-laryngeal tunnel. The robot, sophisticated and expensive, makes it possible to shorten this long curve of laparoscopic techniques.

CONCLUSION

LT-TO techniques are well-described, reproducible, and less surgically aggressive than LTCE, its equivalent in open surgery. We consider that technology allows us to make a classic technique such as LTCE even less invasive.

There is a need to accumulate clinical experience in LT-TO, which is currently scarce for TORS and almost anecdotal for TOUSS and MCL, and to demonstrate that the lower aggressiveness of the technique translates into fewer complications and better functional outcomes.

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