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LARYNGOLOGY

Transoral laser exoscopic surgery of the larynx: state of the art and comparison with traditional transoral laser microsurgery

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SUMMARY

Objective. To evaluate the efficacy of transoral laser exoscopic surgery (TOLES) in a unicentric series of patients affected by benign and malignant glottic and supraglottic lesions, and compare outcomes with those of transoral laser microsurgery (TOLMS).

Methods. To demonstrate the non-inferiority of TOLES in terms of operative time, margin status and complication rates, we compared outcomes of 93 patients treated by TOLES between July 2021 and July 2023 with those of a match-paired group of 107 historical patients treated by TOLMS. To perform a multiparametric ergonomic evaluation of TOLES *vs* TOLMS, we used observational methods for biomechanical overload risk assessment and wearable technologies comparing 15 procedures with TOLES *vs* a paired match of 13 surgeries performed with TOLMS by the same surgeon.

Results. No significant differences were found in terms of surgical duration, positive margins, or complications between TOLES and TOLMS. Ergonomics assessment by inertial measurement units and electromyographic surface electrodes demonstrated a reduced biomechanical overload with TOLES compared to TOLMS.

Conclusions. The many advantages of TOLES, such as its superior didactic value, better digital control of light even through small-bored laryngoscopes, improved binocular vision, and increase in surgical performance by 3 or 4-hand techniques, are difficult to be quantified. In contrast, its non-inferiority in terms of oncological results and better ergonomics compared to TOLMS are demonstrated herein.

KEY WORDS: transoral surgery, exoscope, microscope, larynx, oncologic outcomes, ergonomics

Introduction

In the last two decades, technological advancements in the field of minimally-invasive laryngeal surgery have led to the development of new devices and instruments aimed at improving laryngeal visualisation during transoral procedures and enhancing surgical manoeuverability inside the narrow space of the operative laryngoscope. Especially for removal of premalignant and early-intermediate tumours of the glottis, supraglottis, and hypopharynx, a number of different techniques have been used, ranging from traditional transoral laser microsurgery (TOLMS) [1] to transoral ultrasonic surgery (TOUSS) [2], transoral robotic surgery (TORS) [3-4] and, more recently, transoral laser exoscopic surgery (TOLES) [5], which represents the target of the present comparative study. TOLES is based on a novel visual technology known as "exoscopy", which is driven by recent advancements in endoscopic cameras. The term "exoscopy"

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refers to the use of an external digital device designed to improve the visualisation of the surgical field by delivering high-definition imagery, strong illumination and excellent magnification [5]. Its use in laryngeal surgery was first conceived in 2011 by the Storz company. However, at that time, the image of the surgical field was presented in only two dimensions, thus leading to a significant loss of image depth and surgical limitations in the accomplishment of fine, minimally-invasive endolaryngeal manoeuvers [6]. Subsequently, in 2017, the VITOM 3D exoscope system (Karl Storz, Tuttlingen, Germany) was released, which, in contrast, allows for a three-dimensional (3D) perception of object volume and structural depth, enabling more precise control of fine movements, and enhancing hand-eye coordination by using dedicated glasses that allow to see the surgical field on a wide screen [7-9].

This technology has been first applied to limited surgical series, mainly in the fields of neurosurgery [10-11] and urology [12]. In otorhinolaryngology, an increasing number of studies have demonstrated a growing interest in exoscopic surgery, mainly in otoneurosurgery [13], oropharyngeal surgery [14], and reconstructive microvascular techniques [15], showing various advantages over the traditional gold standard, i.e., the operative microscope. The known advantages of exoscopic surgery include improved ergonomics, reduced operator fatigue, the ability to provide high-quality, collaborative visualisation for the entire surgical team with the possibility to perform a 3- or 4-hand technique, and the possibility of adding real-time filtered wavelengths [5].

The aim of this study is to evaluate the efficacy of TOLES in a large unicentric series of patients affected by benign and malignant glottic and supraglottic lesions, comparing outcomes with those of the gold standard TOLMS. In particular, we focused on two aspects: 1) establish the non-inferiority of TOLES in the treatment of laryngeal diseases, in terms of operative time, margin status and complication rates; 2) perform a multiparametric ergonomic evaluation of TOLES to quantify its improvement in comparison to TOLMS using observational methods for biomechanical overload risk assessment and wearable technologies.

Materials and methods

A prospective analysis of consecutive patients treated with TOLES between July 20, 2021 and July 20, 2023 by a single surgeon (C.P.) was conducted at the Department of Otorhinolaryngology – Head and Neck Surgery, University of Brescia, Italy. Surgical procedures were performed by a VITOM 3D coupled with a Lumenis Ultrapulse Encore 60 (Santa Clara, California, USA) with superpulse delivery in continuous mode (1 to 5 Watts) and an Acuspot 712 micromanipulator (270 μm spot size). The holding system was represented by an ARTip Cruise robotic arm (Karl Storz, Tuttlingen, Germany).

Informed consent was collected and signed by every patient of the study. Inclusion criteria were: a) age older than 18 years; b) benign or neoplastic laryngeal lesions amenable to transoral resection. Exclusion criteria were: a) patients unfit for transoral surgery because of difficult/impossible laryngeal exposure (as preoperatively assessed by the Laryngoscore [16] and/or its simplified version, the mini-Laryngoscore [17]); b) simple biopsy procedures.

Laryngeal flexible fibreoptic endoscopy was always performed before surgery, both by white light and narrow band imaging (NBI). Surgery was performed under general anaesthesia. After placing the patient in the Boyce-Jackson's position, laryngeal exposure was granted using different kinds of operative laryngoscopes according to the site of the lesion (supraglottic *vs* glottic) and degree of exposure [16]. Depending on the pre- and intraoperative evaluation of the laryngeal disease to be treated, different surgical procedures were performed: a) excision of benign lesions; b) different types of endoscopic cordectomies according to the European Laryngological Society (ELS) classification [18]; c) endoscopic supraglottic laryngectomies according to the ELS classification [19]; d) other functional procedures (i.e. posterior cordotomy, lysis of synechiae).

Demographics, tumour characteristics (histological grading and pathological TNM classification), and treatment-related characteristics (type of surgery performed, type of laryngoscope used, operating time, surgical margins status and complications) were prospectively collected into an anonymous database. Concerning histological margins, R0 was defined as a distance from the lesion > 1 mm, R0 close as a distance from the lesion < 1 mm, and R1 when the surgical margin was involved by at least carcinoma in situ.

Variables included in the analysis were expressed in terms of median, interquartile range (IQR), range of values, and percentages. The main demographics (age at surgery, gender), and pathological features (margin status) were compared using the chi-square and Student's t tests, as appropriate; p values < 0.05 (two-tailed) were considered statistically significant.

Comparisons

In the first part of the study, patients treated by TOLES between July 20, 2021 and July 20, 2023 (N = 93) were compared with a match-paired group of patients treated by TOLMS between April 15, 2019 and July 15, 2021 (N = 107) to demonstrate the non-inferiority of TOLES *vs* TOLMS in terms of operating time, surgical margins, and complication rate.

In the second part of the study, a subgroup of 15 patients treated by TOLES between July 20, 2021 and July 20, 2023 were compared with 13 patients treated in the same time frame by the same surgeon (C.P.) by CO_2 TOLMS with similar diseases and procedures of similar length to assess the ergonomics of the two surgical tools (exoscope *vs* microscope). In particular, these two approaches were subjected to biomechanical overload risk assessment with comparative application of several observational methods proposed by the international literature [20-25]. Each surgery was divided into elementary operations to highlight any dysergonomics present in terms of force engagement, repetitive movements and maintenance of incongruous postures. The duration of the dysergonomic operations was summed to define the total duration of biomechanical overload for each work shift to allow subsequent risk assessment using multiparametric analysis. This was made possible by direct observation and analysis of video footage of the surgeries.

During the execution of the same interventions, in order to evaluate the discomfort of the postures and the muscular fatigue of the surgeon, specific wearable devices including two inertial measurement units (IMUs, WaveTrack Inertial System, Cometa System) and 8 probes for surface electromyography (EMG, Mini Wave Infinity, Cometa System) were used. IMUs were placed on the forehead with an elastic headband and at C7 level via adhesive tape, respectively, in order to acquire the movements of the head with respect to the trunk (Fig. 1). The EMG probes were placed on the right (R) and left (L) sternocleidomastoid, R and L cervical splenius, R and L upper trapezius, and R and L anterior deltoid muscles, representing the muscular structures mainly involved during transoral laryngeal surgery (Fig. 2). A maximal voluntary contractions procedure was defined and used to set the 100% muscular activations and normalise each EMG acquisition with respect to it.

The protocol allowed estimation of head flexion/extension and rotation, and variations in the head posture during surgical interventions. In addition, we were able to assess muscle activation levels, number and duration of activations, and muscle fatigue through median frequency analysis.

Results

Patients

The cohort treated by TOLES consisted of 93 patients (Group A), of whom 80 (86%) were males and 13 (14%) females. Mean age at diagnosis was 63.3 years, with a median of 65.2 (range, 25-86). Of these, 15 (Subgroup A) were also studied with ergonomics evaluation (12 males, 3 females; mean age 61.2 years, median 64.2, range 25-78) and compared with 13 patients (Subgroup B) treated in the same period by CO_2 TOLMS (11 males, 2 females; mean age 62 years, median 63.8, range 30-80).

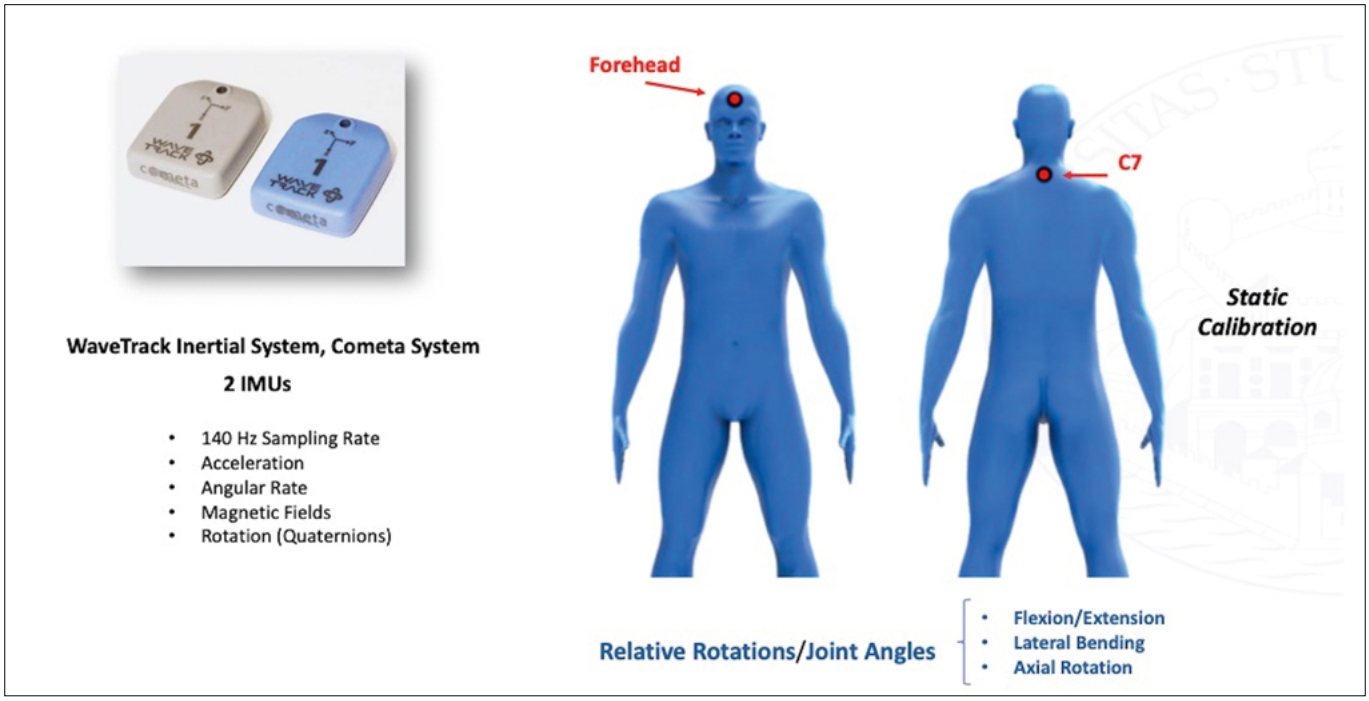


Figure 1. Positioning of the 2 inertial measurement units (IMUs).

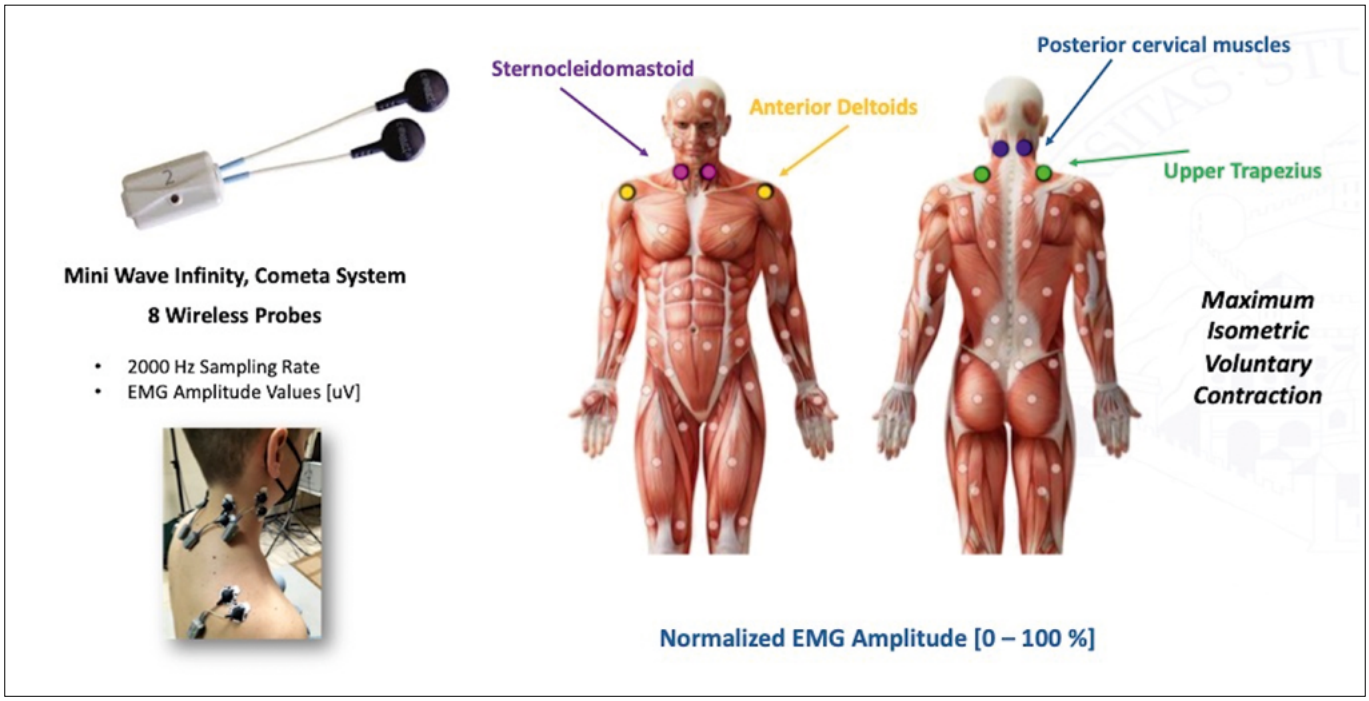


Figure 2. Positioning of the 8 electromyographic (EMG) wireless surface electrodes.

The historical cohort of patients treated by TOLMS between April 15, 2019 and July 15, 2021 involved 107 subjects (Group B), 86 males (80%) and 21 females (20%). In this cohort, mean age at diagnosis was 67 years, with a median of 69.4 (range, 31-97).
No significant differences in terms of age and gender were observed between Group A (TOLES) *vs* Group B (TOLMS) and Subgroup A (TOLES) *vs* Subgroup B (TOLMS).

Lesion characteristics

In both Groups A (TOLES) and B (TOLMS), most surgical procedures were performed to treat oncologic diseases, which included both malignant and pre-malignant lesions. These lesions represented 73.2% of patients treated by TOLES and 67.3% of those treated by TOLMS. In detail, 55 malignant (59.2%) and 13 premalignant lesions (14%) were treated by TOLES, while 62 malignant (58%) and 10 premalignant (9.3%) were treated by TOLMS. According to the 8th Edition of the TNM classification, there was a predominance of glottic pT1a in both cohorts, 25 (45.5%) and 43 (69.4%) in Group A and Group B, respectively. Only 60 patients (25 in the TOLES group and 35 in the TOLMS group) had a benign lesion.
In both groups, neoplastic lesions were predominantly located in the glottic region, 55 (94.6%) and 59 (95.1%) in TOLES and TOLMS cohort, respectively. Only 3 patients in each group had supraglottic tumours. Further details are provided in Table I.

Surgery

None of the surgical procedures performed by TOLES required the support of the operative microscope. According to the ELS classification of cordectomy [18], different types of cordectomy were performed, with Type II being the most common. Further details on surgeries are reported in Table II. In Groups A and B only one complication (postoperative bleeding) was reported. In both cases, these complications were subsequently addressed through a second transoral procedure for revision.
Regarding laryngeal exposure, a large-bored operative laryngoscope was used for 74 patients (79.5%) treated by TOLES. For 17 patients (18.2%), a small-bored operative laryngoscope for difficult laryngeal exposure was needed. A laryngoscope designed for supraglottic lesions was applied in 2 patients (2.3%).
In the TOLMS cohort, 83 (77.5%) and 22 (20.5%) patients were exposed with large- and small-bored laryngoscope, respectively. As for TOLES, a laryngoscope designed for supraglottic lesions was applied in 2 patients (2%).
TOLES had a mean operative time of 58 minutes with a standard deviation (SD) of 30.6 minutes. The median time was 55 minutes. The shortest surgical procedure lasted 14 minutes, while the longest was 165 minutes for a transoral Type IIIa supraglottic horizontal laryngectomy [19].
For TOLMS, the mean operative time was 56 minutes with a SD of 37.7 minutes. The median time was 45 minutes. The

Table I. Characteristics of lesions.

		Group A (TOLES)	Group B (TOLMS)
Type of lesion	Benign	25/93 (26.8%)	35/107 (32.7%)
	Premalignant	13/93 (14%)	10/107 (9.3%)
	Malignant	55/93 (59.2%)	62/107 (58%)
Side of lesion	Right	40/93 (43%)	40/107 (37.4%)
	Left	27/93 (29%)	42/107 (39.2%)
	Bilateral	26/93 (28%)	25/107 (23.4%)
Site malignant/premalignant	Glottic	65/68 (95.5%)	69/72 (95.8%)
	Supraglottic	3/68 (4.5%)	3/72 (4.2%)
Premalignant lesion	SIN1	3/13 (23.2%)	3/10 (30%)
	SIN2	6/13 (46.1%)	4/10 (40%)
	SIN3	4/13 (30.7%)	3/10 (30%)
pTNM			
Glottic	pT1a	25/55 (45.5%)	43/62 (69.4%)
	pT1b	9/55 (16.4%)	7/62 (11.3%)
	pT2	11/55 (20%)	5/62 (8%)
	pT3	7/55 (12.7%)	4/62 (6.4%)
Supraglottic	pT1	3/55 (5.4%)	-
	pT2	-	1/62 (1.6%)
	pT3	-	2/62 (3.3%)

shortest surgery lasted 15 minutes, while the longest was 220 minutes for a transoral Type Vabcd cordectomy [18]. The duration of surgical procedures performed by TOLES was comparable to those carried out by TOLMS (p = 0.684).

Table II. Types of surgery performed.

		Group A (TOLES)	Group B (TOLMS)
Surgery	Cordectomy type I	9/93 (9.7%)	14/107 (13%)
	Cordectomy type II	33/93 (35.5%)	36/107 (33.6%)
	Cordectomy type III	-	6/107 (5.6%)
	Cordectomy type IV	1/93 (1%)	-
	Cordectomy type V	23/93 (24.8%)	19/107 (17.7%)
	Cordectomy type VI	1/93 (1%)	1/107 (1%)
	Endoscopic supraglottic laryngectomy	1/93 (1%)	4/107 (3.8%)
	Excision of benign lesions	21/93 (22.6%)	26/107 (24.3%)
	Others (lysis of synechia/ cordotomy)	4/93 (4.4%)	1/107 (1%)

Surgical margins

As shown in Figure 3, 22% of patients treated by TOLES had positive surgical margins, whereas positive margins were found in 19% of cases for TOLMS. These differences were not statistically significant (p = 0.690).

Biomechanical overload

In Subgroup A, the mean time for TOLES was 43.8 minutes (SD = 17.6), and median time 40 minutes. The shortest procedure lasted 30 minutes (excision of Reinke's oedema) and the longest 90 minutes (Type V cordectomy). Conversely, in Subgroup B, the mean time for TOLMS was 34.3 minutes (SD = 18.3), while the median time was 30 minutes. The shortest procedure lasted 15 minutes (Type II cordectomy) and the longest one lasted 70 minutes (Type I supraglottic laryngectomy). There was no significant dif-

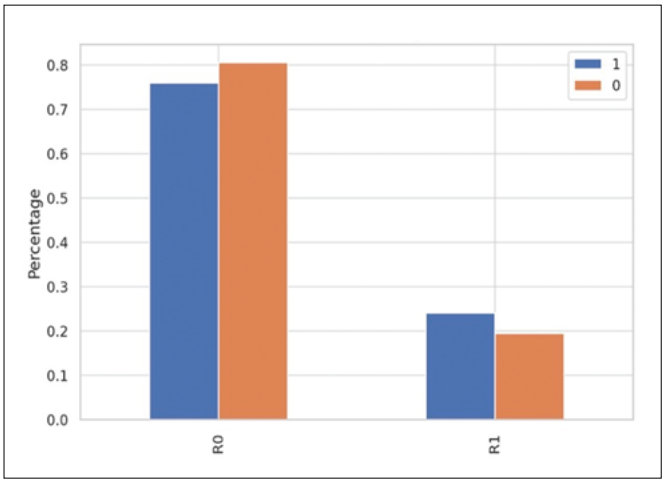


Figure 3. Bar chart representing surgical margin status (R0 *vs* R1) in Groups A (TOLES, blue bar) and B (TOLMS, orange bar).

Table III. Incongruous posture maintenance times for both TOLES and TOLMS and corresponding percentages compared to the total duration of intervention.

	TOLES (Group A)		TOLMS (Group B)	
Shoulders (arms shoulder height, arms not resting, hands above head, elbows above shoulders)	34/1140 sec	2.9%	301 sec/10 min surgery	50%
Wrist (flexion-extension, radio-ulnar deviation)	494/1140 sec 10/1140 sec with force	43% without force 0.8% with force	360 sec/10 min surgery of which 24 sec with force	60% of which 4% with force
Hand-finger (pinch, hook, palm with strength, force, repetitiveness, one-finger use)	855/1140 sec	75% without force	448 sec/10 min 6 sec with force	74% 1% with force

ference between groups for duration of surgery (p = 0.174). In Subgroup A, we used TOLES for one Type I cordectomy, 2 Type II cordectomy, one Type IV cordectomy, 3 Type V cordectomy, and 8 benign lesions. Final diagnosis was benign in 8 lesions, 2 glottic pT1a, one glottic pT2, one glottic pT3, 2 supraglottic pT2, and one glottic pre-malignant lesion. In Subgroup B, we used TOLMS for 2 Type I cordectomy, 4 Type II cordectomy, one Type III cordectomy, 2 Type V cordectomy, one Type I supraglottic laryngectomy, and 3 benign lesions. Final diagnosis was benign in 4 lesions, 5 glottic pT1a, 2 glottic pT2, one supraglottic pT3, and one pre-malignant lesion.
Mean length of procedures was 31 minutes for TOLES (range, 15-80) and 27 minutes for TOLMS (range, 9-78) (p = 0.780).
Table III shows the incongruous posture maintenance times, measured in seconds, of both TOLES and TOLMS and the corresponding percentages compared to the total duration of the intervention. The results show that in TOLMS interventions, biomechanical overload was greater in terms of maintaining dysergonomic positions for the shoulder, wrist, and hand-finger district. The entire hand-wrist complex, in particular, is often employed in pinch actions in both types of approaches.
The risk assessment of biomechanical overload for the operator engaged in the two types of intervention revealed a significant difference between the times of permanence of incongruous posture of the cervical spine: much longer times in interventions by TOLMS, as confirmed by the application of the OREGE method [20]. This is due to the fact that TOLES makes it possible to maintain a head-up posture.

Objective measurement of risk factors

The analysis of the data obtained from the objective acquisitions confirmed what emerged from the risk assessment conducted by observational methods, showing that there are significant differences in the two surgical approaches which affect head posture.
For the kinematics data collected by inertial sensing of the variability of joint angles, i.e., deviation from the mean value, only the ranges of lateral tilt of the cervical spine were significantly greater for TOLMS (p = 0.023), while the range of flexion-extension was reduced in TOLES but with only a trend towards statistical significance (Fig. 4).
The results of the evaluations by EMG showed that during TOLMS the number of muscle activations per minute lasting longer than 5 seconds and of greater intensity than the background noise was greater for 3 of the 4 muscle groups considered: sternocleidomastoid, trapezius, and posterior cervical muscles (Fig. 5). In contrast, the average duration of muscle activations was shorter in TOLES interventions for the sternocleidomastoid, trapezius, and posterior cervical muscles (Fig. 6).

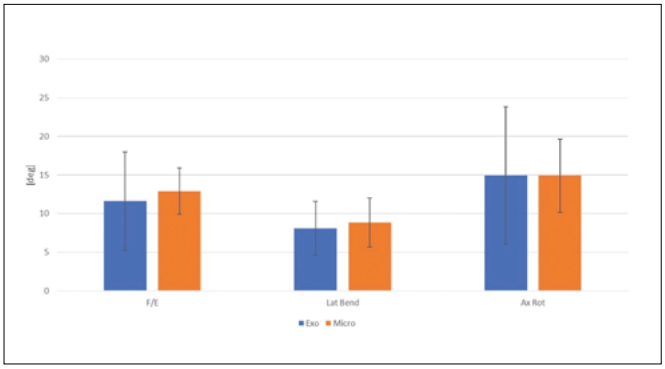


Figure 4. Results of kinematic analysis of cervical spine postures: analysis of variability of head angles relative to the trunk measured by sensors in the two surgical approaches (blue bars for TOLES, orange bars for TOLMS).

Discussion

The recent literature has explored a number of possible surgical applications of the exoscope, primarily in the field of neurosurgery, where this technology is already a reliable alternative to the traditional operating microscope for various spinal and brain procedures [10,11]. The field of otorhinolaryngology has also observed an increasing number of studies utilising this device. Notably, these investigations have explored the potential of exoscopy in otologic [13], oropharyngeal [14], oral, and parotid surgery [26], as well as for reconstructive microvascular techniques [15]. These studies

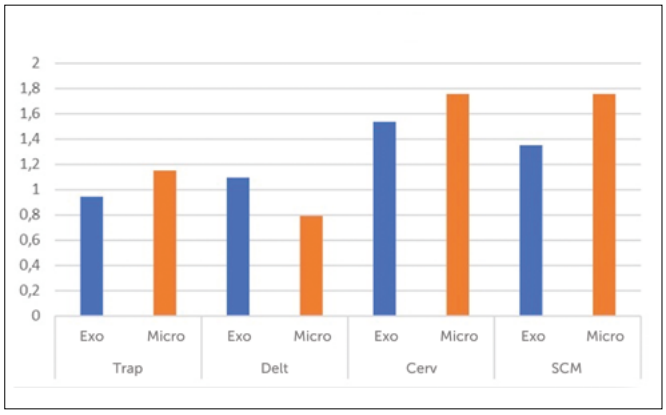


Figure 5. Number of muscle activations per minute lasting longer than 5 seconds and of greater intensity than the background noise (blue bars for TOLES, orange bars for TOLMS).

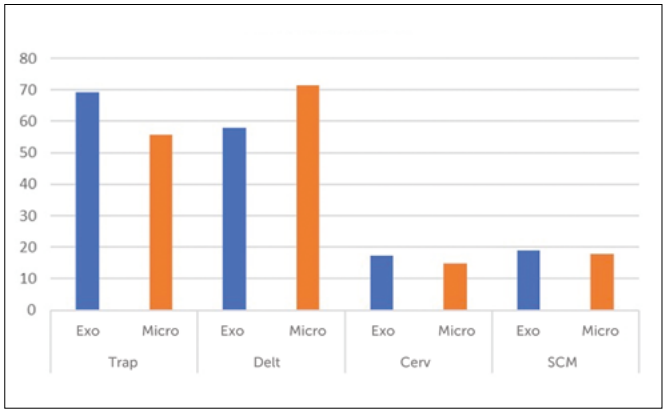


Figure 6. Average duration of muscle activations (blue bars for TOLES, orange bars for TOLMS).

have already demonstrated several advantages over the traditional gold standard, i.e. the operative microscope.

Furthermore, this technology finds application in transoral laser-assisted laryngeal surgery where it facilitates minimally-invasive procedures thanks to a combination of shared high-quality and magnified images with 3D visual perception. The initial experience of Carlucci et al. in 2012 highlighted the feasibility of this technique, even though this was still limited to 2D exoscopic systems which had the shortcomings of representing a step back in comparison to the 3D perception of the surgeon using the operative microscope [6]. Subsequent studies, such as that by Crosetti et al. [14] and Carobbio et al. [7], demonstrated the possibility of coupling a 3D exoscope with a CO_2 free beam laser micromanipulator, thus providing further evidence of the possible advantages of exoscopic technology. Finally, De Virgilio et al. [8] reported their first preclinical experience with the VITOM 3D mounted on an ARTip cruise robotic arm, emphasising the improved visualisation and ease of use during transoral laryngeal surgery. At that point, TOLES was ready for being applied on larger series to test its specific advantages, comparing them in an objective way with those already well-known of TOLMS, still considered the gold standard in this field of application.

The literature highlights the significant advantages of VITOM 3D exoscopic technology compared to traditional instruments. These advantages include, but probably are not limited to, high-resolution 3D visualisation with exceptional illumination under digital control, possibility to intraoperatively shift to filtered lights (Image1 S, Karl Storz, Tuttlingen, Germany) without the need to change the visualisation tool, improved didactic capabilities, possibility to apply a 3 or 4-hand technique, increased manoeuverability, and superior ergonomics with reduced fatigue. This study represents the first unicentric large series addressing some of the above-mentioned issues and trying to compare them objectively with the TOLMS gold standard.

In particular, the assessment of risk of biomechanical overload for the operator engaged in TOLMS *vs* TOLES showed a significant difference between the incongruous posture dwell times of the cervical spine during TOLES, which were found to be much lower compared to those observed during TOLMS. The data obtained from the observational risk assessment were confirmed by the analysis of objective acquisitions, which showed differences in the two surgical approaches, such that they actually affect the head posture and development of muscular fatigue of the upper limbs, although similar patterns of muscle activation were demonstrated. All applied risk assessment methods (observational and objective) agree in showing a reduction in the risk of biomechanical overload to which the surgeon is exposed during TOLES compared with TOLMS.

With the limits represented by the number of acquisitions obtained by objective assessment of risk factors, kinematic analysis showed greater angular deviations of the head during TOLMS. The increased lateral deviations of the joint angles can be explained by the need to bend the cervical spine laterally to interact with the operating room staff, due to the obstruction caused by the microscope. Moreover, the head position during TOLMS resulted in a more frequently "fixed" posture due to the forced alignment of the surgeon's eyes with the microscope eye-pieces and laryngoscope proximal opening. In contrast, during TOLES the monitor is placed in front of the surgeon, who is thus able to view the surgical field unobstructed, keeping a relaxed seated position with a horizontal gaze, aligning the exoscope with the proximal opening of the laryngoscope, thus maintaining an "head-up" position.

The results of EMG evaluations showed that during TOLMS the number of muscle activations per minute lasting longer

than 5 seconds and of greater intensity than the background noise was greater for 3 of the 4 muscle groups considered: sternocleidomastoid, trapezius, and posterior cervical. This finding also appears to be justified by the different arrangement of the instrumentation and consequent differences in movement between the two methods. In contrast, the average duration of muscle activations is shorter in TOLES for the sternocleidomastoid, trapezius, and posterior cervical muscles with significantly higher muscle activation and fatigue of the right trapezius during TOLMS.

The EMG results also show differences between the right- and left-sided muscles, mainly concerning the trapezius and deltoid muscles, which can be explained by the different use of the upper limbs (the surgeon on whom the measurements were taken is right-handed) and the asymmetrical arrangement of the surgical field (the instruments were placed to the right of the surgeon).

In contrast, EMG data for the posterior cervical muscles, which have a predominantly postural role, are difficult to interpret because their activation signal was of similar intensity to that of background noise.

TOLES technology provides further benefits: in fact, it presents high-definition images on an external monitor, enabling the entire surgical team to closely observe the procedure and creating a valuable learning opportunity for nurses and assistants, particularly for those in training. This feature leads to improved workflow, better collaboration among team members, and enhanced educational opportunities in academic settings. Even though such advantages are difficult to be quantified and demonstrated in an objective manner, the overall feeling of residents and young specialists seeing a procedure performed by TOLES confirms this.

Moreover, exoscopic systems can switch between white and filtered light during surgery, significantly improving delineation of tumour margins, especially in cases of upper aero-digestive tract malignancies. Even though the vast majority of the literature concerning the use of filtered lights in transoral laser surgery of the larynx is focused on NBI [27], it is already well-accepted that this correlates with improved precision in surgical resection of tumours, especially when dealing with difficult conditions such as persistent/recurrent diseases after (chemo)radiation [28-30].

Moreover, unlike traditional microscopes, which result in binocular vision loss using small-bored laryngoscopes, the 3D exoscope eliminates this issue thanks to the reduced distance between the two optical systems compared to the larger distance of the microscopic eye-pieces. The possibility to have a better 3D visualisation even through a small laryngoscope, together with the increased illumination under digital control, allows the surgeon to push the limits of operability of lesions with suboptimal laryngeal exposure, without increasing the rate of positive surgical margins [31].

The time required for equipment setup and procedure execution is similar when comparing procedures performed by TOLMS and TOLES, as confirmed by the present series. Similar outcomes have been reported in other areas such as parotid surgery [26], microvascular reconstructive surgery [15], and cochlear implant placement [13].

In the context of surgical treatment of malignant lesions, the focus must remain the oncologic radicality of resection with achievement of negative margins by histological examination. In our case series, there were no significant differences in terms of positive margins between patients treated with TOLES compared with those managed with TOLMS. Future larger series from other centres will allow additional comparisons.

Conclusions

Exoscopic surgery has progressively evolved and TOLES represents one of the most promising applications of this novel technology to the field of transoral resection of laryngeal lesions. The accumulating evidence of its advantages, including improved ergonomics, educational value, and the addition of filtered light, as well as its non-inferiority in comparison to the gold standard TOLMS for benign and malignant laryngeal pathologies, render exoscopy a promising alternative to traditional microscopic techniques.

Conflict of interest statement

Authors declare no conflict of interest.

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Author contributions

CP, ES, NFL: concept; FG, CM, GZ, ES: data collection; CP, FG, CM, GZ, ES: writing – original draft; CP, DL, FDB, ES, GDP, NFL: writing – review and editing.

Ethical consideration

This study was approved by the Institutional Ethics Committee (CE Spedali Civili) (protocol number: 4267). The research was conducted ethically, with all study procedures being performed in accordance with the requirements of the World Medical Association's Declaration of Helsinki.

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