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Glottic configuration changes and outcomes of endoscopic arytenoid abduction lateropexy

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Abstract

Introduction Endoscopic arytenoid abduction lateropexy (EAAL) is an effective glottis enlarging procedure for the treatment of bilateral vocal cord palsy (BVCP). The postoperative glottic configuration changes can be evaluated by modern, high-resolution, 3D image reconstructions. Functional results are described by spirometry as well as objective and subjective phoniatric tests.

Methods Unilateral EAAL was performed in ten malignant thyroid gland tumor patients (eight women, two men), who had BVCP after thyroid surgery. Slicer 3D® software was used for morphometric analysis. Pre- and postoperative peak inspiratory flow (PIF) and standard phoniatric parameters were compared.

Results The glottic gap improved significantly (+ 60%). Significant improvement of PIF was found in all cases. Phoniatric tests revealed better quality of voice and patient satisfaction. Their voices changed from a severely impaired to a socially acceptable, almost normal, quality.

Conclusion The results support our clinical observations that the ideal position of the lateralization sutures is the one which provides a physiological abduction position of the arytenoid cartilage. Considering these good results, the surgical indications for minimally invasive endoscopic arytenoid lateropexy may be extended.

Keywords Bilateral vocal cord palsy · Endoscopic arytenoid abduction lateropexy · 3D reconstruction

Introduction

The treatment of bilateral vocal cord palsy (BVCP) presents a great challenge currently, considering the multifactorial etiology, the difficulty to predict outcomes, the expectation of the patients, and the possible surgical approaches. The latest publications have shown that there are an increasing number of temporary palsies and a high percentage of the synkinetic mobility disorders along with permanent palsies. Because of these findings, the commonly used endoscopic surgical approaches of arytenoidectomy and transverse cordotomy/cordectomy, which are based on balancing improved breathing against voice loss [1], are being replaced by dynamic solutions for BVCP [2, 3]. Reinnervation procedures [4–6] and newly reintroduced laryngeal pacing techniques [7, 8], can only benefit a larynx which has not been treated with destructive techniques. Thus, while many still consider tracheostomy is necessary for patients during the acute phase and the first year of BVCP, an alternative concept may be the use of endoscopic suture arytenoid abduction lateropexy, which preserves the laryngeal structures and improves the airway without the need for tracheostomy with its attendant risks. This procedure provides reversibility, in the event of vocal fold motion recovery, along with the immediate improvement of the glottic airway. It also ensures good postoperative phonation in those not rare cases in which the vocal fold motion fully or partially recovers [11].

The common approaches using destructive options to treat BVCP cannot be easily compared clinically because of the relatively small numbers and statistically non-comparable study groups [9]. In our previous morphometric study (100 cadaver larynges), the outcomes of popular endoscopic

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procedures were each being performed on the same cadaver larynx allowing for an objective evaluation [10, 11]. In this study, the endoscopic arytenoid abduction lateropexy (EAAL) was shown to be a structurally favorable solution by providing breathing improvement without contributing to the deterioration of voice quality compared to other methods. But, these theoretical results need to be supported by objective clinical studies.

Modern, non-invasive high-resolution imaging procedures (computer tomography, magnetic resonance imaging) could be a useful tool for similar in vivo morphometric analyses [12]; the post-surgical functional improvements from the glottic reconfiguration can be measured. Moreover, spirometric and phoniatric tests can provide objective data, validating the functional clinical results [13–15].

Methods

Patients and materials

Ten patients, who underwent bilateral thyroidectomy because of malignant thyroid gland tumors in other surgical specialists, were recruited. The study population was made up of eight women and two men with a mean age of 57 years (± 12.8 years SD). Each patient had postoperative BVCP with no history of any preoperative hoarseness and/or dyspnea. Eight patients had moderate or severe postoperative dyspnea, two patients could not be extubated after thyroid surgery because of suffocation. The BVCP required rapid intervention consisting of unilateral endoscopic abduction arytenoid lateropexy (EAAL), which was performed in the manner of our earlier publications [16, 17]. Endolaryngeal thread guide instrument (ETGI; Mega Kft, Szeged, Hungary) was used in the EAAL. The average time between the thyroid surgery and the glottis enlarging procedure was 2.1 days (range 0–8 days). The side for lateralisation (7 left, 3 right sided) was determined by the surgical chart describing the intraoperative thyroid surgery conditions, especially any details indicating the possible injury of one versus the other recurrent laryngeal nerve.

In our previous morphometric publications [10, 11], the efficacy of different suture glottis enlarging procedures were evaluated in 100 fresh cadaver larynges. To compare the clinical in vivo 3D CT reconstructions, ten 'similar' cadaver larynges of the same gender and antero-posterior (AP) diameter were chosen for study.

Analysis of postoperative laryngeal configuration: 3D CT reconstructions

All of our thyroid tumor patients required postoperative CT for follow-up, so unnecessary radiation exposure was

avoided. CT scans were taken in the postoperative 1st–10th month (mean of 3.8 months).

CT image work-up

CT scans with 0.5 mm slice thickness were performed. This resolution made it possible to obtain a good three-dimensional reconstruction of the glottic chink. Slicer 3-D® [18] open source software was used for the anatomical reconstruction of the glottic airway. The horizontal slices were applied for the 3D reconstructions. The optimal range of the Hounsfield Unit (HU) was between − 130 and − 800. Imaging was not a part of our clinical preoperative protocol in patients in need of EAAL for BVFP because of the urgency of the procedure. We reasoned that probable preoperative glottic parameters (such as distances, angles, areas and volumes) could be estimated by doubling the values of the non-treated side of the glottis. These data could be objectively compared to the actual postoperative results, and thus the efficacy of the procedure was able to be evaluated without a physical exam.

Glottic volume measurement

The upper and the lower borders of the glottis were marked and 12 slices representing a 6 mm of thickness of the airway volume were evaluated. This glottic airway volume was measured in cubic millimeters.

First, the mid-sagittal plane was determined. Then, the volume of the non-treated side (theoretical preoperative status) and the volume of the operated side were measured. The calculated preoperative volume was the doubled volume of the untreated side to the midsaggital line. The postoperative total volume was directly measured.

Glottic area measurement

The calculated preoperative and the measured postoperative half glottic areas (the operated side) were compared (Fig. 1). The half glottic areas were derived from glottic volumes at the narrowest gap between the cords corresponding to the free edge of each side. The preoperative area was calculated using the area of the non-treated side to the midsaggital line as explained above.

Glottic geometrical measurements

The angle of the anterior commissure and the maximal deviation from the midline was measured in both cadaver laryngeal images and three-dimensional reconstructions of patient larynges (Fig. 1b, c). First, the midline of the larynx was marked, it was the line between the anterior commissure and the midline of the inner surface of the cricoid

Fig. 1 Glottic configuration after left side EAAL. **a** Cadaver larynx (female, 68 years, 18 mm AP diameter). **b** Three-dimensional reconstruction of the glottis (28 years, female, 18 mm AP diameter), the thyroid and the arytenoid cartilages in blue, the lateralized half glottis area in yellow, and the non-treated side in orange. **c** Analyzed parameters: half glottis area (the lateralized half glottis area: pale blue, and the non-treated side: green); angle of the "half" anterior commissure (red alpha: left side, black beta: right side); maximal deviation of the vocal process from the midline (red arrow: left side, black arrow: right side)
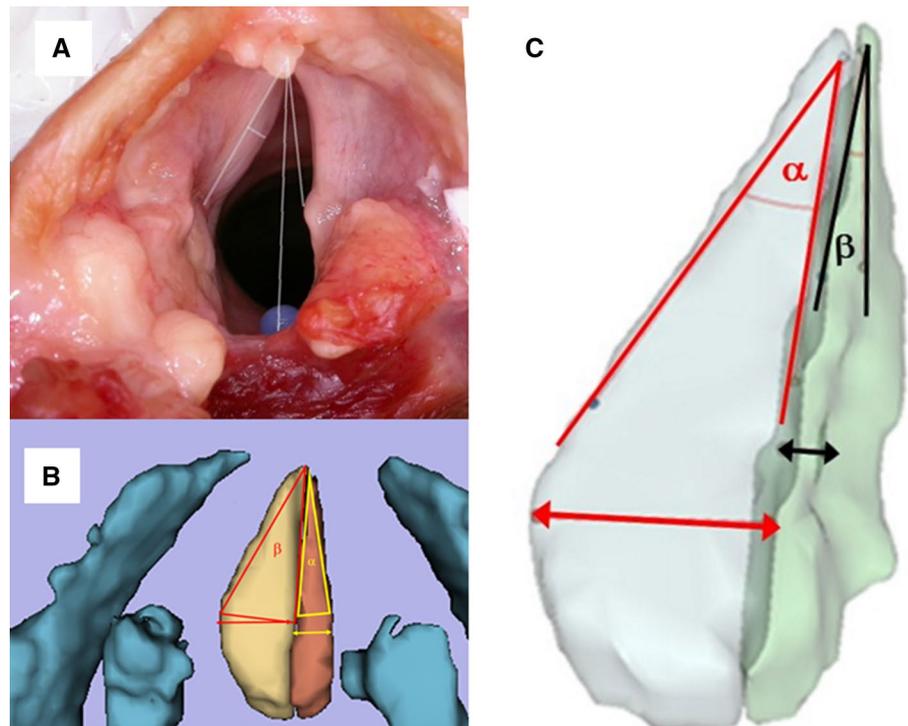
cartilage. The midline divided the unoperated and the lateralized side of the larynx. The maximal glottic deviation (in millimeters) was the distance of the air shadow between the midline and the most lateral point of the examined glottic side. The value was measured in this way because these maximal distances were not at the same antero-posterior position, since the EAAL pulls the arytenoid cartilage more posteriorly (Fig. 1b). The angle of the anterior commissure was the calculated preoperative value compared to the actual value of the operated glottis (Fig. 1c).

Functional outcomes: spirometry and phoniatric tests

The peak inspiratory flow (PIF) was measured in all patients. Preoperative tests—if possible—were made on the day before the operation. Postoperative measures were established on the first postoperative week and the third postoperative month. Thor Soft SpiroTube—PC Spirometer (THOR Laboratories Budapest, Hungary, Bogdanfy str. 10A, H-1117) was used in the study.

Because of severe dyspnea or intubation of the patients, preoperative examination could only be performed in six out of ten patients. Although all of the ten persons participated in the postoperative functional tests, only pre- and postoperative of six patients could be compared.

The recording of the patients' voice was analyzed by Praat software (Boersma and Weenink, 2009) and the Tascam US 122 MkII PC audio interface (TEAC America, Inc.

1834 Gage Road Montebello, CA 90640). The preoperative voice—if possible—was recorded on the day before the operation. The patients were instructed to produce a sustained vowel [a]. A postoperative recording was obtained in all patients at 3 months postoperatively. The objective phoniatric parameters of jitter, shimmer, maximum phonation time (MPT), fundamental frequency (perceived as pitch), and harmonics to noise ratio (HNR) were examined at each session.

Statistical analysis (pairwise comparisons; repeated measure ANOVA; Sidak adjustment for multiple comparisons) was performed using SPSS 20.0.

Results

Figure 1 shows that the same postoperative glottic configuration was found in cadaver and 3D reconstruction groups.

After EAAL, the breathing of all patients improved significantly. None of them required any other airway maintenance. This is consistent with the findings that all of the examined morphometric parameters of the airway were found to be significantly larger in the side which had undergone lateralization with EAAL (Fig. 2). Significant improvement of peak inspiratory flow (PIF) was found in all cases after EAAL (Table 1). We observed a correspondence between the improvement of the glottic configuration and the improvement in PIF. The improvement in the
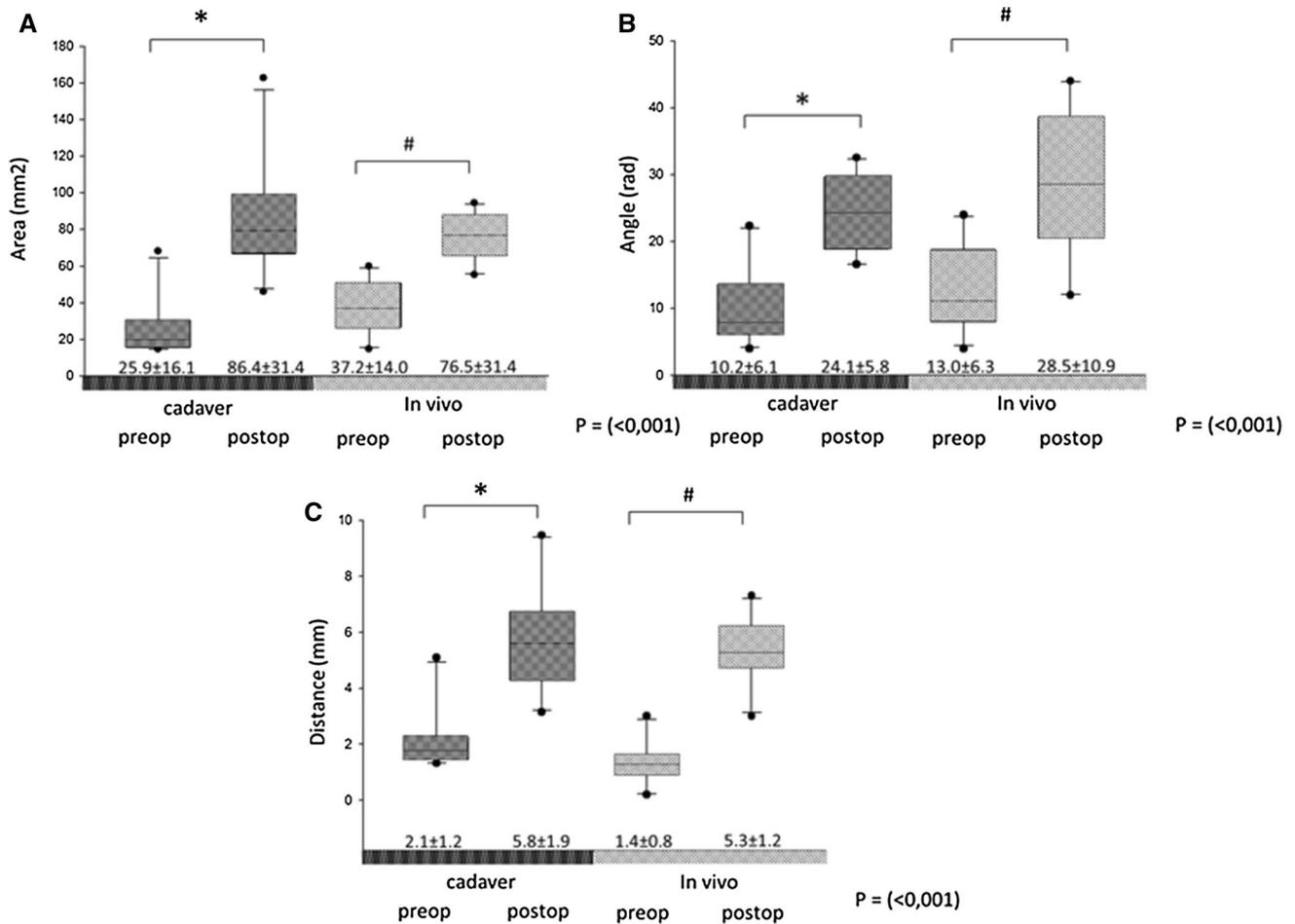
Fig. 2 Comparison of the lateralized half and the untreated half glottis. The examined parameters: area, anterior angle, maximal deviation

Table 1 Spirometric results of EAAL ($n=6$)

	Preoperative	Early postop (1 week)	Late postop (3 months)
PIF (%)	0.96 ± 0.3	1.51 ± 0.4	2.11 ± 0.5 ($P = <0.001$)

Table 2 Changes of the glottic volume after unilateral EAAL ($n=10$)

	Preoperative	Postoperative	P
Glottic volume (mm³)	355.8 ± 195.2	541.6 ± 239.0	<0.001

glottic volume represents a realistic, three-dimensional change of the glottic space (Table 2).

The quality of patients' postoperative voice was found to be significantly better: jitter, shimmer, HNR and MPT values all improved. The fundamental frequency (F_0) decreased. HNR and F_0 were in the normal range (Table 3).

Table 3 The changes of the acoustic parameters of the voice ($n=6$)

	Preoperative	Early postoperative (1st week)	Late postoperative (3rd month)
Jitter	6.26 ± 2.3	3.81 ± 1.7	0.76 ± 0.1 ($P=0.004$)
Shimmer	21.03 ± 5.2	9.69 ± 3.74	5.79 ± 2.3 ($P=<0.001$)
MPT	2.44 ± 1.67	5.81 ± 2.8	9.23 ± 3.9 ($P=0.005$)
F_0	240.35 ± 112.2	206.55 ± 39.1	209.49 ± 18.3 ($P=<0.001$)
HNR	2.91 ± 1.1	7.85 ± 3.3	16.78 ± 6.8 ($P=<0.001$)

Shimmer (dB or %, normal range is <7%)

MPT (maximum phonation time, seconds, normal range varies with age and gender—in this group it would be roughly 15 with a SD of 5)

F_0 (fundamental frequency relating to pitch, Hz)

HNR (harmonics to noise ratio, in dB, normally an increase in the number indicates a purer quality in the voice)

Significant changes are labeled with bold letters/numbers

Jitter (%variability, normal range < 1%)

Discussion

According to cadaver morphometric studies [10, 11], endoscopic arytenoid abduction lateropexy (EAAL) proved to be a very effective suture-based lateralizing procedure for the treatment of bilateral vocal cord palsy (BVCP), and we propose that these good results are reproducible in real patients.

The development of modern imaging technology provides a great opportunity for non-invasive morphometric measurements [19–21]. During conventional computer tomography, the detector and X-ray tube unit are rotated round the fixed examination table. The modern helical CT enables quicker image processing. Because the examination table is moved through the continuous radiation source, a large number of slices can be made during one breath hold. It is especially advantageous in a diagnosis involving the airways because the artifacts resulting from respiratory movements can be ruled out. The total length of the trachea can be scanned within 30–50 s [22–26]. The advanced multi-slice CT system is equipped with multiple parallel detectors to obtain even thinner slices [25]. The high resolution and the less than 1 mm thickness of slices make precise analysis of even small organs possible [23, 26, 27]. In the larynx, the arytenoid cartilages and surrounding soft tissues are almost isodense to the radiation. According to Bakhshaee, the radiologic basis of arytenoid reconstruction needs plenty of post-imaging corrections with very high-definition CT scanning using 0.6–1 mm slice thicknesses [28]. The correct marking of the maximal deviation of the vocal process which determines the vocal cord's position, requires precise radiographic segmentation of the arytenoid cartilage.

The evaluation of the airways in early childhood is a great challenge. Yunus applied helical computed tomography 2D and 3D images, and virtual endoscopy in the evaluation of airway disease in neonates, infants and children. The accuracy of virtual endoscopy and 3D reconstruction was 98%; the classic 2D helical CT imaging provided 86%. He concluded that these methods could replace conventional endoscopy in the assessment of airway disease without any additional risk [20]. Burke found that this method was suitable for analyzing fixed airway lesions, but it seemed to be less useful in cases of dynamic, functional stenoses [19]. If, for example, a patient with BVCP could not "hold their breath" during the scan or were to be inhaling/exhaling during the study, variability would be introduced to position of the cord edges. Basically, air flow in any direction through the glottis alters the position of these tissues and, as a consequence, would alter the calculated area of the airway.

The postoperative CT scans allowed for the reconstruction of the glottic airway because of the high difference in density of laryngeal tissues and air. Therefore, the glottic air shadow could be easily segmented using the optimal range of Hounsfield Unit [20, 22]. By choosing the appropriate range of density, a three-dimensional model of the airway could be visualized. The real-sized air shadow could be analyzed from different views, so precise morphometric measurements were possible. All of the parameters that we used in our previous surgical anatomical cadaver study [10, 11] could also be measured in real patients.

Hiramatsu performed a study reconstructing the larynx during inspiration and voicing. The horizontal scans were made while their patient inhaled and phonated for 2 s. Their findings about glottic movements were similar to ours. The inhaling position of the vocal process is more lateral, posterior and superior (similar to the position after EAAL) compared to the vocal process of the paralyzed side [29].

Pulmonary function tests have become an indispensable tool for the clinical evaluation of respiratory health and disease since the 1970s. They play an essential role in the diagnosis and management of respiratory diseases, especially asthma and chronic obstructive pulmonary disease (COPD) [30, 31]. Kashima [32] and Cantarella [33] found that inspiratory flows were significantly reduced in unilateral upper airway paralysis; whereas, with the exception of peak expiratory flow (PEF), the expiratory flows were in the normal range. However, Dursun [34] found forced expiratory volume at 1 s (FEV1), FEV1/FVC (forced vital capacity) and PEF values significantly reduced, studying bilateral paralysis. According to Vössing [35], PEF was the most sensitive parameter. It was more sensitive in detecting extrathoracic obstruction than did peak inspiratory flow and there would be a more reliable parameter; though he was looking at structural or scar-based stenosis, not paralysis-based obstruction.

The simple PIF spirometric test can be easily performed before and after the operation. It is useful for monitoring the resistance of the upper airways through pliable tissues like the vocal folds. In our patients, an immediate significant PIF value improvement was detected after the procedure and the late results were often even better. This further improvement could be explained by the diminishing of the postoperative laryngeal edema and the advanced overall physical condition of patients.

The pathophysiology of vocal cord paralysis is not completely understood despite the numerous meticulous animal and human studies [33, 36]. According to the literature, intraoperative stretching and thermal damage are the main causes of laryngeal function degeneration associated with thyroid surgery [1, 37]. Some degree of reinnervation can often be observed later, which generally ranges from the complete recovery of the vocal cords to poorer

outcomes with different types of synkinesis or total permanent paralyses [36].

Although in the literature the transverse cordotomy is considered historically to be one of the most voice-preserving interventions [36], the postoperative voice can be expected to be deteriorated compared to the normal voice. According to Harnisch et al. [38] and Dursun et al. [34], the early postoperative phoniatric outcomes are worse. They do improve over time, but the parameters never reach the normal range.

In our previous cadaver studies [10, 11], EAAL was shown to be one of the most effective suture lateralizing techniques in the literature. In our current study, the 3D reconstruction results were similar. EAAL provided a large glottic gap immediately. Moreover, the phoniatric results were consistent with the results of Harnish's and Dursun's studies [34, 38]. MPT, HNR and F_0 were similar, and the 3 months postop aperiodicity values of jitter and shimmer were even further improved in our study compared to the results of Harnish and Durson [34, 38]. EAAL provides a tensed and straightened vocal cord and, thus, a more favorable configuration for phonation than the midline and flaccid preoperative condition.

Conclusion

Analysis of postoperative high-resolution CT scans proved the efficacy of endoscopic arytenoid abduction lateropexy (EAAL). Significant improvement of the glottic area was found.

Spirometry, objective and subjective phoniatric tests showed an improved postoperative condition as well. The postoperative voice became acceptable, the physical endurance improved, which meant that both main functions of the larynx, breathing and phonation, could be preserved. The patients became satisfied with their condition.

Compliance with ethical standards

Conflict of interest Authors declare that they have no conflict of interest.

Human and animal rights statements All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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