Partial laser arytenoidectomy in the management of bilateral vocal fold immobility

A modification based on functional anatomical study of the cricoarytenoid joint

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ABSTRACT

Objectives: To establish the anatomical relationships of the arytenoid and cricoid cartilages and apply these findings to design an arytenoidectomy based on a sound anatomical basis.

Methods: We prospectively conducted this study between 1996 and 2002 at the Main University Hospital of Alexandria, Egypt. In 50 patients, we endoscopically measured the length of the vocal process and the distance between the vocal process tip and upper border of the cricoid cartilage. We sagittally and axially sectioned 25 total laryngectomy specimens to verify the position of the arytenoids and their relation to the cricoid. The anatomical findings led to the design of a laser partial arytenoidectomy and cordotomy (L-PAC), which we used in 45 patients with bilateral cord paralysis in adduction.

Results: The anatomical findings showed that the cricoarytenoid joint did not contribute to the airway in any of the measured specimens. Using L-PAC, we decannulated 100% of the patients and no patient needed postoperative tracheostomy at any time. Only 3 patients experienced minimal postoperative aspiration to liquids (6.7%). We achieved reasonable phonation as assessed by a speech analysis battery. However, 3 patients (6.7%) needed contralateral L-PAC.

Conclusion: The present extra-articular technique, L-PAC, showed its superiority to previous endoscopic or transcervical complete arytenoidectomy techniques in providing an effective balance between the protective, respiratory, and to a lesser extent the phonatory functions.

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Bilateral vocal fold immobility in adduction has been for several decades a challenge to the laryngologist. Although transcervical approaches have been advocated since the turn of the century, however, it was not until 1948 when Thornell[1] described the first endoscopic management. Transcervical approaches were either through mid-line thyrotomies to approach the vocal fold, arytenoids, cricoid cartilage or through lateral exposure of the cricoarytenoid joint for either arytenoidopexy or an arytenoidectomy. Airway improvement was achieved at the expense of voice quality in most cases and associated with an increased risk of aspiration in few instances.[2-4] Other transcervical approaches included attempts for neurorrhaphy and laryngeal reinnervation using the spinal accessory, the ansa

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(descendens) hypoglossi, collaterals of recurrent laryngeal nerve, phrenic nerve and Tucker's operation.[5-7] In 1982, Talaat[8] published the results of 15 years experience with use of transcervical microscopic arytenoidectomy in 35 cases compared to 15 cases of laser total arytenoidectomy, for the management of bilateral vocal fold immobility in adduction with superior results of transcervical arytenoidectomy. Whichever technique is used for widening the larynx at the glottic level, there are certain anatomical facts must be taken into consideration: 1. in vocal fold paralysis the anteroposterior diameter of the larynx is reduced due to loss of the muscle power approximating the cricoid and the thyroid cartilage, second; 2. the inner anteroposterior and transverse diameter of the cricoid are the least in dimensions, and 3. the cricoid facets and the cricoarytenoid joint are variable in dimensions looking at different directions leading to asymmetry of the position of the arytenoids on the cricoid.[9,10] Accordingly, widening of the airway at the glottic level is restricted by the airway dimensions at the inner aspect of the cricoid cartilage and the position of the arytenoids, whether medial or lateral, dictated by the shape of the cricoid.

The aim of this work was to detect the anatomical relationships of the arytenoid to the cricoid focusing on the relationship of the cricoarytenoid joint with the airway and to apply our findings to design an arytenoidectomy based on sound anatomical findings.

Methods.

This study was prospectively conducted between 1996 and 2002 at the Main University Hospital of Alexandria, Egypt. Institutional review board approval was obtained for this study.

Anatomical study. Fifty patients with non-malignant laryngeal lesions, admitted for direct laryngoscopy under general anesthesia to the Main University Hospital of Alexandria, Egypt were subjected to endoscopic measurement of the length of the vocal cord and vocal process on each side, distance between the tip of the vocal process and cricoid cartilage posteriorly, and distance between the tip vocal process of the arytenoid and upper border of the cricoid cartilage in the coronal plane passing through the former (**Figure 1**). A special endolaryngeal ruler with a bayonet handle was designed for the latter endolaryngeal measurements. Twenty-five total laryngectomy specimens without cancer involvement of the glottis were sagittally and axially sectioned to verify the position of the arytenoids and their relation to the cricoid. The following points were assessed: contribution of the cricoarytenoid joint to the airway; the position of the tip of the vocal process to the widest transverse dimension of the cricoid cartilage, and the shape of the cricoid cartilage. Patients who presented with bilateral vocal cord immobility for less that one year were excluded from the study.

Laser partial arytenoidectomy and cordotomy (L-PAC). From mid June 1996 until mid June 2002, 45 patients with bilateral vocal fold paralysis in adduction underwent PAC using CO_2 laser. Thirty-eight women and 7 men with age ranging from 15 – 87 years (48 $\pm$15 years) were included in this study. Fifteen patients have had tracheotomies on presentation for more than 9 months and less than 1 year. Two patients have had tracheotomies for more than 8 years, one patient for 6 years and one patient for 3 years. The rest of the patients were not tracheostomized at presentation, they had mild stridor but their main problem was exertion intolerance.

Technique of partial arytenoidectomy and cordotomy (**Figure 2**). A continuous super-pulse $C0_2$ laser beam was used at 99 kHz, at 7-10 watts power, using a spot size of 0.8 mm. Three main steps were conducted as follows: 1. A transverse cordotomy at the level of or just anterior to the vocal process, completed in a perpendicular axis to the anteroposterior plane of the vocal cord, down to the cricoid arch. The mucosa, vocal ligament, cricovocal ligament, vocalis muscle and the medial fibers of the thyroarytenoideus muscle were cut through the full thickness of the fold reaching laterally to the sagittal plane of the medial border of the cricoid cartilage and inferiorly to upper surface of the cricoid. During the latter cut, the muscles recoil and retract anteriorly. 2. A lateral cordotomy then starts at the lateral most point of the transverse cut. The laser beam was directed forwards in curvilinear fashion parallel to the superior edge of the cricoid arch in the same latter plain anterior to the transverse cordotomy. This second cut caused further retraction of the vocal fold anteriorly and laterally. 3. Posterior extension of the lateral cordotomy to involve muscles juxtalateral to the vocal process and extending the latter cut across body of the arytenoid, going to its medial aspect. The inner aspect of cricoid arch and its continuation as the cricoid lamina were used as guidelines and as the posterior limit of the third cut. The laser was directed to cut through the muscles lateral to the arytenoid cartilage, and through the arytenoid itself, flush with the cricoid reaching to its medial aspect. Thus, the vocal process, cricovocal ligament and muscles lateral to it, and the part of the arytenoid anterior to the inner aspect of the cricoid will be resected as one mass in a 3-dimensional orientation creating a PAC. Postoperative assessment was carried out for all patients stressing on: 1. Subjective improvement of respiration. The exercise tolerance was measured by the ability of the patient to climb 2 levels stairs and walk 2 kilometers, on 2 separate occasions, without dyspnea, provided that his heart

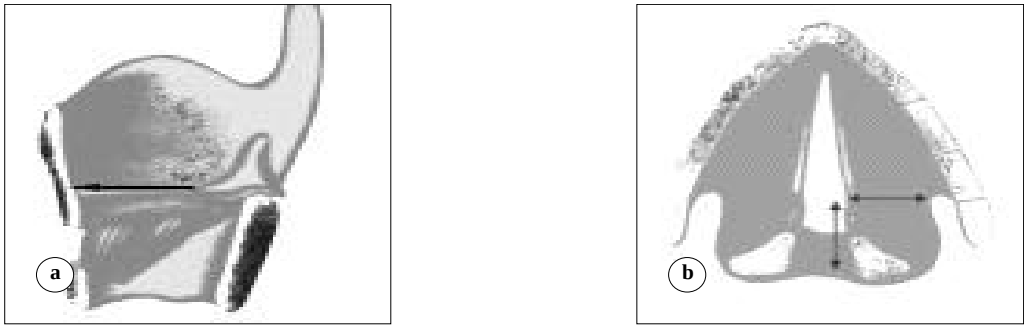

Figure 1 - Parameters measured during this study. **(a)** Length of vocal process and vocal fold. **(b)** Distance between the tip of the vocal process and the cricoid cartilage laterally and posteriorly.

Table 1 - The relation between the gender and different measurements of normal adult larynx.

Parameter	**Range**	**Mean ± SD**	**r**	**F**	***p***
Right vocal fold (Membranous portion)	11-26	18.74 ± 3.71	0.779	0.695	0.3383
Left vocal process (Membranous portion)	11-26	18.79 ± 4.01	0.784	0.0003	0.9956
Vocal process to cricoid posteriorly	7.83-9.6	13.75 ± 4.08	0.753	5.23	0.043
Vocal process to cricoid laterally	5.7-16.8	11.25 ± 5.52	0.792	22.07	0.0002
Cricoid AP			0.625	30.358	0.0001
Male (n =13)	14-22.5	18.69 ± 1.31			
Female (n = 12)	14 - 19	16.25 ± 1.545			
Cricoid T			0.824	12.207	0.0024
Male (n = 13)	12-22.5	19.38 ± 1.46			
Female (n = 12)	12-18	15.38 ± 1.583			

AP - anteroposterior measurement, T - widest transverse measurement

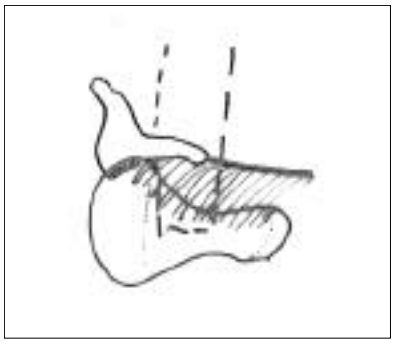

Figure 2 - Resected part of the vocal process and body of arytenoid anterior to the cricoid cartilage (PAC).

Table 2 - Voice analysis results.

Speech parameters	**Mean+ SD**
Maximum vocal intensity	57.4 ± 7 dB
Average fundamental frequency	282.47 ± 156,58 Hz
Jitter (%)	13 ± 3.5
Shimmer in dB	6.7 ± 5.3
Shimmer (%)	22.7 ± 8.1
Degree of voice break	0.52 ± 0.5%
Number of voice break	0.5 ± 0.2
Number of sub-harmonic segments	17.48
Total pitch period detected	537 ± 174

and lung conditions allowed. 2. Postoperative aspiration. 3. Flexible nasopharyngolaryngoscopy on regular intervals. 4. Voice analysis 3 months postoperatively comparing maximum vocal intensity (MVI), average fundamental frequency, jitter (%), shimmer in dB, shimmer (%), degree of voice break, number of voice break, number of subharmonic segments, total pitch periods detected.

Statistical analysis. The range and the mean ± SD were calculated. Then correlation coefficient r was estimated and confirmed by simple regression analysis and analysis of variance, to identify the relation between the specified variables and their probability.

Results. ***Anatomical results.*** Regarding the shape of the cricoid cartilage, it was found to be ovoid (type I) in 40% of cases, oval (type II) in 32% of cases, pear shaped (type III) in 20% of cases and narrow oblong (type IV) in 8% of cases (**Figures 3 & 4**). The mean anteroposterior diameter of the cricoid cartilage was 18.69 ± 1.31 in males and 16.29 ± 1.545 mm in females (p=0.0001), while the transverse diameter was 19.38 ± 1.46 mm in males and 15.381 ± 1.583 in females (p=0.0001) (**Table 1**).The cricoarytenoid joint, was not found to be related to any section to the airway. The facet of the joint on the cricoid was always found in a posterosuperior and lateral position (**Figure 5**).The mean length of the vocal process was 9.3 ± 0.5 mm. The relation of the vocal process to the widest dimensions of the cricoid was found to be dependent on the shape of the cricoid. The average distance between the tip of the vocal process and cricoid laterally was 11.25 ± 52 and 13.75 ± 4.08 posteriorly (**Figure 6**) (**Table 1**).

The laser partial arytenoidectomy and cordotomy results. None of the 45 patients needed a postoperative tracheostomy. All patients were extubated and or decannulated on the operating table except 2. These 2 patients, an 87-year-old man and a 66-year-old woman, were markedly obese with COPD and coronary artery disease, and were gradually decannulated over a 72-hour period postoperatively. Only 3 patients (6.7%) suffered minimal postoperative aspiration to fluids, which resolved spontaneously within 2 weeks period. All patients achieved the ability to walk more than 2 kilometers and climb 2 levels of stairs without dyspnea. Postoperative flexible laryngoscopy revealed a patent airway with complete healing within 4 weeks postoperative. A minimum follow-up period of 2 years was available. Postoperative airway distress occurred in 2 cases (4.4%) secondary to granulation tissue, which resolved with mitomycin application. Three patients (6.7%) needed contra lateral L-PAC.

Speech analysis. Using a computerized speech analyzer 27 parameters were obtained for each patient. **Table 2** shows the mean and standard deviation of the 9 most important parameters. Maximum vocal intensity (MVI) was 57.4 ± 7 dB with a low fundamental frequency, yet the degree and number of voice breaks were quite reasonable.

Discussion. Undoubtedly, the cricoid is the narrowest part of the airway after the glottis. In addition, it has been well documented that the position of the arytenoids on the cricoid although variable from one person to another, is symmetrical, and their position limits the width of the normal glottic shank posteriorly.[9,10] Our study demonstrates that the cricoid has 4 main configurations (types I-IV) in its axial orientation. Types II and IV are the narrowest posteriorly creating a naturally narrow glottic shank, with the widest transverse dimensions of the cricoid being at the level of the mid cord. Failure to recognize this specific cricoid configuration may lead to failure of any procedure directed towards widening the airway by only addressing the arytenoid. This scenario dictates widening the glottis at the mid cord level, at the expense of the membranous part. Such a widening ought to preserve the vocal fold bulk and at the same time it is created at the widest cricoid transverse dimension. As long as the vocal process forms an average of 40% of the vocal fold,[9] the mid cord will be just anterior to the vocal process of the arytenoid. It has to be mentioned that the whole length of the vocal fold in adults varies from 20-23 mm in males and from 16-28 mm in females. These findings are similar to those of our study. The latter variability extends to professions, with opera singer having longer cords (30-33 mm in basses and 21-25 mm in tenors), and to ethnicity where Taiwanese having shorter cords than Italians.[11] Another interesting anatomical finding of the present study was that the cricoarytenoid joint did not contribute to the airway in a single case in which serial sectioning of the larynges was performed, and that its cricoid facet looked always in a lateral and posterior direction. Thus, resecting any part of the arytenoid posterior to the anterior edge of the cricoarytenoid joint will not add any width to the airway, as the inner aspect of the cricoid, lying anterior to the joint, is a limiting element. Accordingly, any resection or ablation of the arytenoid needs to be extra-articular, anterior to the joint. Measurements from the tip of the vocal process to the cricoid upper border posteriorly and laterally, showed a wide dimension in the coronal plain, which is almost just behind the mid cord level. Thus, the widening at the level of the vocal fold to be effective needs to be carried out just anterior to the vocal process. Reidenbach[12] described 3 complexes related to the arytenoid; a loose connective tissue complex (CTC) formed by the vestibular fold, a dense CTC formed by cricoarytenoid ligament and conus elasticus, and

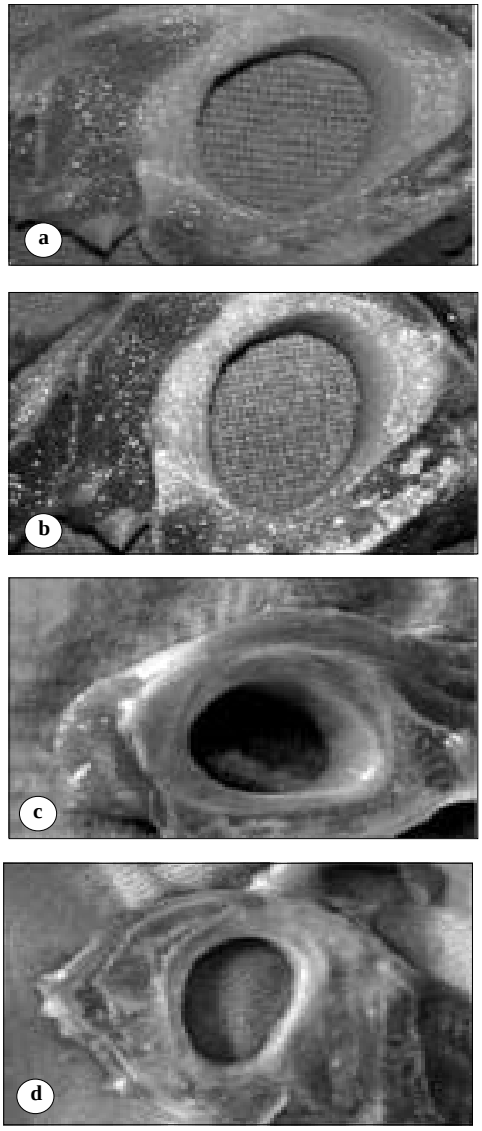

Figure 3 - Different configurations of cricoid cartilage: **(a)** Type I - ovoid, **(b)** Type II - oval, **(c)** Type III - pear shaped and **(d)** Type IV - narrow oblong.

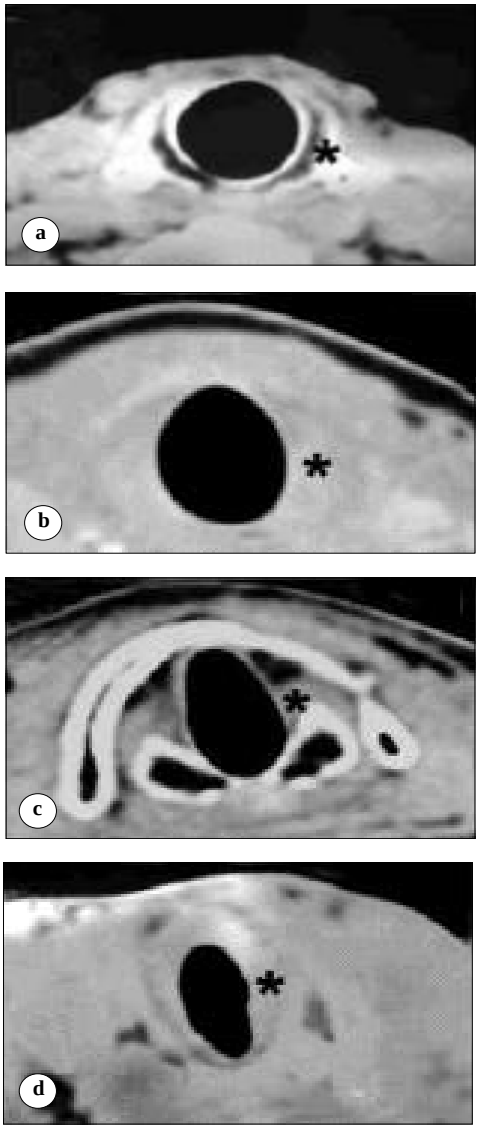

Figure 4 - Axial CT scan at the level of the cricoid and cricoarytenoid joint showing different configurations of the cricoid cartilage, **(a)** Type I: Round, **(b)** Type II: Oval, **(c)** Type III: Pear shaped, **(d)** Type IV: Narrow oblong. (*cricoid cartilage).

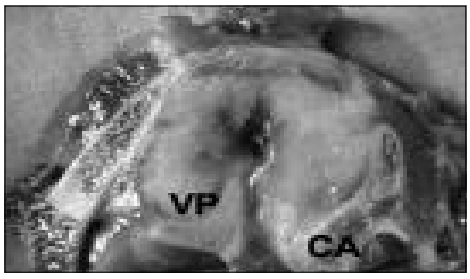

Figure 5 - Axial cut section of the cricoid cartilage at the level of the cricoarytenoid joint showing that the joint is not related at all to the airway. (CA - Cricoarytenoid joint, VP - vocal process of arytenoid).

Figure 6 - Mean length of the vocal process and the distance between the tip of the vocal process and the lateral margin of the cricoid cartilage.

a muscular complex formed by the transverse arytenoideus and thyroarytenoideus. Our work documents the importance of the fourth complex; the cricoarytenoid cartilaginous complex, dominated by the configuration of the cricoid and the location of its widest transverse dimension, centered around the vocal process of the arytenoid and its merge with the body, excluding the cricoarytenoid joint. Accordingly, a preoperative assessment of the cricoid cross-sectional configuration by CT scan is an integral part of the patients' workup. It will decide whether the glottic widening ought to be taken more towards complex I and III anteriorly rather than depending on partial arytenoidectomy limited in benefit by for example a type II or IV cricoid configuration. The present technique adopted in this work, solves the latter conflict. It revolves around the fact that the cricoid is the limiting factor for any airway widening above it, whether at the glottic or supraglottic levels. Widening beyond the inner aspect of the cricoid or away from its widest diameter is not beneficial. If the vocal process of the arytenoid is considered as the cartilaginous portion of the vocal fold, then any arytenoidectomy will involve a cordectomy. Our technique involves 2 cordotomies and an extra-articular arytenoidectomy. Thus, a classification for arytenoidectomies can be suggested as follows: 1. Peri-articular (the whole arytenoid is removed = total arytenoidectomy) that can be conducted transmucosally[13] or submucosally.[14] 2. Intra-articular.[15] 3. Extra-articular: (cricoarytenoid joint is preserved = partial arytenoidectomy) including Medial arytenoidectomy[16] and PAC. According to the present technique, total and subtotal arytenoidectomy are unnecessary as our findings strongly suggest that the cricoarytenoid joint does not contribute to the airway. In addition, removing the arytenoid solely will not lead to a real widening of the airway if the cricoid was a type II or IV configuration. A medial arytenoidectomy will remove the vocal process, yet it may not resect enough tissue to restore an adequate airway, evident by the need for contralateral medial arytenoidectomy after a few months in good percentage of cases.[16] Further evidence that a total arytenoidectomy adds minimally to air way widening, is provided by the study by Eckel and Vossing[17] who documented that a cordectomy offers a glottic widening that is 3-4 times more than that offered by an arytenoidectomy. Postoperatively, speech analysis for the patients subjected to L-PAC showed a maximum phonation time similar to that previously reported by Remacle et al[15] who analyzed only 4 parameters in 13 patients (10 males and 3 females) with both gender lumped together as one group after subtotal arytenoidectomy. There was no statistically significant difference between males and females according to our findings with a low fundamental frequency as expected, reasonable percentage of voice breaks and subharmonic segments , after L-PAC. It has to be noticed that the voice outcome after cordectomy or arytenoidectomy is quite unpredictable.[17] Yet, Eckel and Vossing[17] showed that final voice evaluation revealed reduction of maximum phonation time, peak sound pressure levels and frequency range in all their 28 patients, but phonatory results varied considerably. The latter finding concur with those of the present study. Minimal aspiration occurred in 6.7%, lasting for 2 weeks only, and recurrence of exercise intolerance occurred in 3/45 patients operated, with a primary success 93.3% for L-PAC. The present study subjectively and objectively assessed the patients postoperatively, with results superior to that reported by Gupta et al[18] for laser cordectomy (80%) and lateralization with (70%) or without arytenoidectomy (66%), or those reported for laser ventriculocordectomy (76.2%) by Pia et al.[19] Our results mimics those of Laccourreye et al,[20] who used laser endoscopic posterior partial transverse cordotomy (EPPTC) to revise their unilateral cases, obtaining a primary airway restoration in only 68% of the cases. The latter group found on analyzing their data by univariant analysis, that age, gender, cause of paralysis, laser parameters, duration of postoperative antibiotic or steroids were all not statistically related to success. On the other hand, bilateral EPPTC is more likely to be successful in airway restoration than unilateral EPPTC (p=0.018) according to their findings.

In conclusion, the present study highlights the importance of the cricoid cartilage configuration for the success of any glottic widening procedure, and the choice of an ideal site for executing a transverse cordotomy. In addition, it proved that the only part of the arytenoid, which when resected can contribute to airway restoration is the vocal process and the adjoining part of the arytenoid body, anterior to and outside the cricoarytenoid joint. The L-PAC has been designed bearing in mind the above anatomical findings and those of other authors. It is an extra-articular procedure that can be carried out in a day surgery step-up except in very few cases. It allowed anterior and lateral extension of the widening procedure according to the location of the widest transverse cricoid dimension. The L-PAC proved to provide an effective balance between the protective, respiratory, and to lesser extent the phonatory functions of the vocal folds.

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