OPTIMALISATION OF ENDOLARYNGEAL THREAD GUIDE INSTRUMENT (ETGI) FOR VARIOUS ANATOMICAL CIRCUMSTANCES – AND APPLICATION ITS RESULTS IN THE INFANT AIRWAYS

Ph.D. Thesis

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Ph.D. Thesis

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ABBREVIATIONS

AP	Antrio-posterior
BVCI	Bilateral Vocal Cord Immobility
BVCP	Bilateral Vocal Cord Palsy
CAJ	Cricoarytenoid joint
CT	Computer tomography
EAAL	Endoscopic Arytenoid Abduction Lateropexy
E.G.	Exemplī grātiā ("for example")
ETCO2	End-tidal CO2
ETGI	Endolaryngeal Thread Guide Instrument
ETT	Endotracheal tube
HFU	Hounsfield unite
HNR	Harmonic Noise Ratio
Hz	Hertz
LEMG	Laryngo-elecro-myography
MF	Mechanical fixation
PACS	Picture Archiving and Communication System
PGS	Posterior Glottis Stenoses
PICU	Perinatal Intensive Care Unit
QQL	Questioner of Quality of Life
SD	Standard deviation
TC	Thyroid cartilage
TM	Transvers midpoint
TP	Transverse posterior
VP	Vocal process

CONTENT

1. INTRODUCTION

Bilateral vocal cord immobility (BVCI) is a term used to describe vocal cords that are restricted secondary to neuropathy, muscular disorders, or mechanical fixation (MF) [1]. The moderate to severe dyspnea generally requires surgical intervention. Their solution is considered to be one of the most difficult fields in laryngology. In the past decades several open and endoscopic surgical techniques were introduced for the treatment. It is a 'hot topic', according to the PubMed database 1975 publications have been listed under only the label, the ''bilateral vocal cord/fold paralysis'' until now.

Our work group has been working on the treatment of upper airway stenosis for more than 20 years. We published various surgical solutions [2-8] for stenosis of different etiology: uni- and bilateral vocal cord paralysis and mechanical cricoarytenoid joint's fixation causing posterior glottis stenosis. The 'key factor' of our surgical concept is a glottis enlarging technique, the endoscopic arytenoid abduction lateropexy (EAAL) [2]. The mobile or mobilized arytenoid cartilage is tilted and fixed into its physiologically most abducted position, which cause large 'glottis opening', vocal cord lateralization. In vocal cord paralysis the procedure produce immediately wide airway, in case of glottic stenosis the bilateral temporary lateralization prevents restenosis.

In previous cadaver studies [3, 4] EAAL was compared to other popular glottis enlarging techniques. It proved its efficacy: provided the largest glottic space, the postoperative glottis configuration was beneficial to preserve the patients' voice quality. In the past years more than 400 patients were treated successfully with EAAL, our clinical results were accepted for publication in prestigious journals as well. We introduced a complex clinical results' [3, 4] evaluation panel for these surgeries (spirometry, phoniatric tests, Quality of Life Questionnaire).

However, to perform a perfect arytenoid abduction the ideal lateralization suture position is necessary. Nevertheless, in vivo the correct creation of this fixating loop location is practically impossible by existing needle carrier devices or through externally inserted needles. Therefore, a new endoscopic thread guide instrument (ETGI) was designed [2]. The configuration of male, female and pediatric larynges is so different, that no single device is suitable for all. Modern, high resolution imaging techniques (MRI and CT) provide really

good opportunity for measuring the most important parameters of laryngeal configuration in living subjects relatively easily. The other option would be a cadaver study, however, besides the well-known technical and legal problems; in these cases the post mortem changing and destruction of tissues deteriorate the results.

These images could help to optimize ETGI device with different size and shape for males, females and also for young children, because the difficulties arisen from the wide variety of laryngeal configurations require different endolaryngeal parts of the device. These parts are commutable, this study makes it possible to design different sizes of blades and stems which overlap these laryngeal individualities.

In our team's earlier publications we have introduced the efficacy of this concept on adults. In the second, clinical part of the study I would like to demonstrate the results of our concept in the most difficult and vulnerable population, in the neonatal larynx.

During my active working period in the Department of Otorhinolaryngology, Head and Neck Surgery, University of Szeged from 1998 till 2001 under the supervision of *Professor Jenő Czigner*, *Professor József Jóri* and *Professor László Rovó*, I joined the 'airway stenosis surgical team'. I participated in several different upper airway stenosis surgeries.

One of my main tasks was the endoscopic examination of the complex movement of cricoarytenoid joint and analysis of cervical configuration in order to introduce the Endolaryngeal Thread Guide Instrument (ETGI) for EAAL. Commutable parts and blades were designed for the instrument suitable for almost all laryngeal configurations. In my opinion it has opened new doors and provided a great opportunity for minimal invasive microlaryngeal surgery.

1.1. GLOTTIS STRUCTURES' LATERALIZATION PROCEDURES

The history of SURGICAL PROCEDURES [66] includes the followings:

- resection of anatomical structures
- retailoring and displacing the existing structures, with minimal tissue removal
- displacing existing structures, without tissue resection
- restoration or substitution of the missing innervations of the laryngeal musculature

Procedures, which utilize suture loop(s) for lateralization of glottis structures alone or in combination with other resection methods, can be traced back to the beginning of the 20th century [11].

1.1.1. Extra-laryngeal approach

Erwin Payr (Vienna) [11] described the endo-external procedure and the paralyzed vocal cord was sutured to the thyroid ala. *Rethi* [11] found the outcome of this procedure uncertain, however, in his first suggested procedure it was applied as part of his concept in 1922. Via laryngofissure (median splitting of thyroid and cricoid cartilage) approach a curved incision was made starting from the incisura interarytenoid below the vocal cord then the lateral thyroarytenoid, the interarytenoid and the lateral cricoarytenoid muscles were exstirpated. The cricoarytenoid joint was opened, well preserving the arytenoid cartilage and the overlying mucosa. In one of his modifications after muscle extirpation the overlying mucosa and the arytenoid were adapted and sutured temporarily over a rubber tube placed on the skin of the neck for days till the healing process was completed. The mobilized arytenoid cartilage was turned with the vocal process in lateral position in this way. External procedures made from lateral approach (lateral trans-thyroid or behind the posterior edge of thyroid cartilage) have become more popular. These procedures left the mucosal line intact so the risk of infection could be diminished which was a significant factor especially before the modern antibiotic era. Moreover, the direct targeting of arytenoid cartilage (partial or complete arytenoidopexy) provided better results: dilating more effectively the respiratory glottis and left the phonatory structures mainly intact.

One of the earliest techniques is *King's* transposition of the omohyoid muscle to the arytenoid cartilage [12], which could produce only a passive abduction not the improved motility, as it was primarily expected. *Woodman* [13] suggested the suturing of the vocal process to the inferior horn of thyroid cartilage following subtotal arytenoidectomy. *Newman* [14] used a window on the thyroid ala at the level of the thyroid joint for the lateralization of the vocal process. The vocal cord remained at the level of the contralateral side facilitating a better voice production. The later modifications with the complete preservation of the arytenoid cartilage have become popular from the 1970's. These techniques leave the

laryngeal mucosa maximally undisturbed, so in 50-80% of the cases preliminary tracheotomy became unnecessary [9, 15] which was considered to be obligatory in the earlier interventions.

Schobel's technique [9] consists of preservation of the posterior crico-arytenoid ligament as a hinge as well as turning and tilting of the arytenoid cartilage laterally. It is held in this position with three permanent retention sutures, two of them armed with heavy knots. These knots reinforced the lateral rotation of the arytenoid cartilage. These sutures run in the sub mucosa horizontally along the anterior surface of the arytenoid cartilage and are fixed through burr holes on the posterior margin of the thyroid cartilage. In the majority of cases the operation could be performed under local anesthesia, which helped to establish proper voice function.

In 2007, *Woodson* and *Weiss* [16] described a simplified surgical method for this concept considering the physiological abduction axis of the joint attaching the muscular process of the arytenoid by a suture to the inferior horn of the thyroid cartilage. This leaves largely intact the periarytenoid musculature, which might be advantageous for the dynamic voicing in partial recovery of paralyzes. These latter, really effective procedures seem to be advantageous even in pediatric cases, although their application is generally not the first of choices nowadays because of the relatively long and challenging surgical intervention, their high tracheostomy dependency and their potentially low reversibility.

1.1.2. Endolaryngeal Approach

Cancura [17] in 1969 reported on endoscopic laterofixation technique with wires passed through under and over the vocal cord from the laryngeal cavity out to the skin by a bend pipe and a drill. Then a third wire was pulled in through the oral cavity into the larynx and out of the skin by knotting its ends to the previous ones. This made a creation a lateralizing wire loop possible.

In the clinical practice ten years later *Kirchner* [18] introduced the endolaryngeal lateralization of the vocal ligament after the removal of a pre-assessed amount of thyroarytenoid muscle with laryngeal microcautery. A temporary suturing technique was described with guided nylon sutures by two externally inserted needles. An endoscopic

guided the nylon thread from the lower needle to the upper one to form a loop around the vocal process. After the withdrawn of the needles padded buttons were used plus lead fishing sinkers to adjust the tension and secure these sutures on the surface of the neck. In his study, all patients required tracheostomy.

Ejnell et al. [19] reported on his first case series with a similar technique of permanent simple suture lateralization but without any resection of glottic structures. The thread was tightened just outside of the cartilage from a larger external incision. Using a small endotracheal tube the tracheostomy could be avoided. The long term reliability was also proven by the team [20].

In 1983, *Lichtenberger* [21] introduced a needle carrier device (*Richard Wolf Medical Instruments*, Knitlingen, Germany), which was designed for his endo-extralaryngeal concept. The procedure was capable of passing a needle and suture endolaryngeally through the thyroid to the skin, significantly simplifying and making the loop creation around the vocal processs more precise [5, 22-24].

In 1997, *Jóri et al*. [23] reported on a successful application of a modification of the *Lichtenberger's* procedure for acute vocal cord immobility. The effect was essentially similar to *Ejnell et al.'s* [19, 25] method but their cases demonstrated that the fixing thread could be inserted more easily and precisely this way. The fixing thread was buried and knotted above the prelaryngeal muscles from a 1 cm skin incision instead of the originally suggested 5-6 cm, [25, 26] so the atrophy of the cartilage could be avoided without the use of an external silicone platelet.

The more than twenty-year experience with this concept, however, has revealed the possible complications as well. According to *Tucker* [27] the major drawback is the slipping of suture and tearing the mucosal part of the vocal cord resulting in remedialization in the long run.

For reducing the rate of the compilation and achieving better surgical results the exact movements of cricoarytenoid joint were studied.

1.2. ANALYSIS OF CRICOARYTENOID JOINT MOVEMENT

Going back to the history of CAJ movement *Galenus* (A.D 130-201) explained the closing and opening of the larynx by medial and lateral gliding of the arytenoid cartilages on the joint part of the cricoid cartilage [28]. *Willis*, in 1829, described the motion of the joint as a forward and backward rocking of the CAJ [29]. *Morris, Mcmurrich* [30] and *Piersol* [10] described it as the combination of three separate movements, forward- backward, outward and inward gliding and rotating and twisting around a vertical axis in 1907. In the international literature the well-known theory that explained the motion of the joint as a turning around a simple vertical axis comes from *Negus* (1929) [31]. *Sonneson* [32], *Von Leden* and *Moore* [33], *Ardran* and *Kemp* [34] , *Fink* [35] described more complex rotational movement of CAJ.

Wang [36] has convincingly demonstrated that during abduction the lateral sliding motion of the vocal process is accompanied by an upward and occasionally slightly posterior movement simultaneously, with the arytenoid cartilage turning laterally and upward on the cricoid cartilage facet. On full abduction the arytenoid cartilage lies laterally at the upper and outer cricoid facet, having moved superiorly, posteriorly, and laterally.

These - more or less contradictory - theories are generally based on the top-view picture of the larynx during motion, on the examination of only a few anatomical preparations, on passive movement of the joint or electric stimulation of isolated intrinsic muscles of the larynx. The hidden position and the soft tissues covering the joint do not allow direct examination.

In a previous publication digitally processing the shots made by endoscopes, analyzing and averaging the images, the changing positions of the arytenoid cartilage during ab- and adduction were shown. Adding the results to the findings of modern anatomical examination we could define the realistic movements of CAJ [7].

1.3. ENDOSCOPIC ARYTENOID ABDUCTION LATEROPEXY (EAAL)

Endoscopically inserted suture which directly lateralizes the arytenoid cartilage to the normal physiological abducted position [2] may provide long-term dependable results.

In our earlier cadaver studies, performed on one hundred fresh cadaver larynges, we proved that EAAL provided the most beneficial glottis configuration compared to other suture lateralizing techniques [3, 4]. In vivo larger glottic gap, and larger posterior commissure angle might lead to better breathing; smaller anterior commissure angle and tensed vocal cords might preserve better the patients' voice.

Nevertheless, in vivo the correct creation of this more posterior fixating loop location is practically impossible through an externally inserted needle [19] or by the original *Lichtenberger's* device [21] because the thyroid cartilage is more dense in that area.

For this reason a new thread guide instrument has been designed for safe, accurate, and fast suture loop creation for the endoscopic arytenoid abduction lateropexy (EAAL) [2].

The efficacy of this device, the postoperative clinical results mainly depends on the maneuverability in the larynx and the ideal suture position for tilting the arytenoid joint into abducted position. The anatomy of male, female and children larynx is so different that no single instrument would suit for them. The laryngeal size, shape, thickness and density of cartilages differ very much.

Analysis of the high resolution cervical CT scans provides good possibility for non-invasive measurement of the laryngeal structures. Based on this study different size blades for male's, female's and children's larynx were designed. With this instrument in the past years more than 300 adult BVCP patients were treated by EAAL. Similar clinical results could be achived as we had in cadaver studies. Our surgical methods and clinical results introduced for adult BVCI were published in prestigious journals.

1.3.1. A New Thread Guide Instrument for Endoscopic Arytenoid Lateropexy

The principle of the endolaryngeal thread guide instrument (ETGI) is the utilization of a built-in, movable curved blade with a hole at its tip (**Fig. 1**) allowing a suture thread to be guided in and out between the exterior surface of the neck and the internal laryngeal cavity. The stem of the instrument is a rigid steel pipe, curved at its distal, blade-holding end, created to fit into midsized, closed laryngoscopes. The second component is a rod, largely cased within the steel pipe stem. At the uncased proximal end of the rod is a freely rotating finger clip. At the distal end of the rod is the curved blade, appropriately designed to fit the

curvature of its stem casing. The connection between the blade and the rod is fixed but flexible, ensuring forceful blade movement on exit and re-entry of the curved stem end. The pull and push of the finger clip (with the thumb) causes the in-and-out blade movement from the stem end. At rest, the blade is inside the curved stem end. The third component of the instrument is the ergonomic handle, which also serves as a shaft to hold the instrument in a straight position. The steel stem of the instrument is fixed to the handle with a clamping screw after turning it to the desired direction. The structural rigidity of the ETGI ensures easy penetration through the thyroid cartilage. The device has the approval of the Hungarian Health Care Institute [37].

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Figure 1: The endolaryngeal thread guide instrument (ETGI).

The parts of the ETGI (the blade is pushed out). b = The built-in, movable, curved blade in a pushed-out position with a hole at its tip. s = steel pipe stem; r= rod; h= handle; c = clamping screw; f = finger clip

1.3.2. Surgical procedure

General anesthesia combined with supraglottic jet ventilation is suggested. For the sake of maneuverability, the larynx is exposed with a *Weerda* laryngoscope (**Fig. 2A**) or with a *Macintosh* laryngoscope (in three females with difficult direct laryngoscopy). In cases of MF a strong, right-angled, saber-shaped scythe designed by our team is used for dividing the

adhesions in CAJ, which is completed with CO2 laser scar excision in posterior glottic stenosis (PGS) [8]. In cases of BVCP unilateral EAAL was performed, and in cases of MF bilateral EAAL was performed.

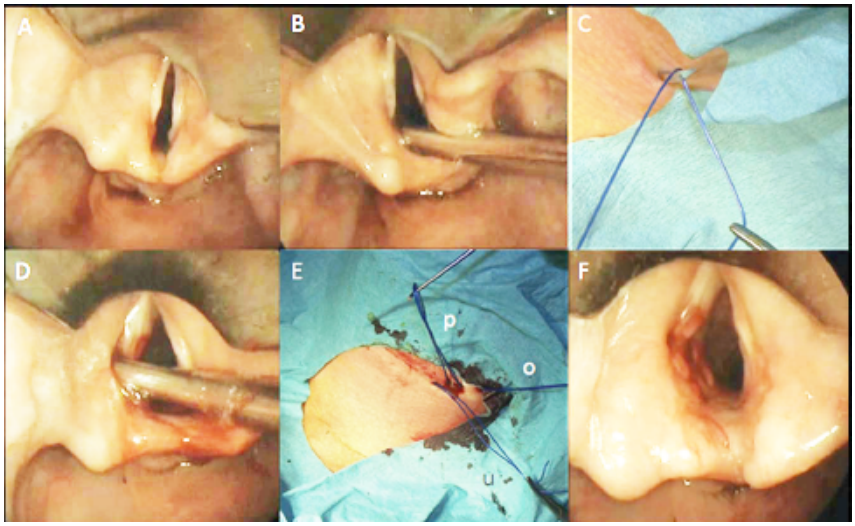

Figure 2: Intraoperative pictures of a 67-year-old female

Pictures demonstrate the efficacy of the method even in a small female larynx (see detailed explanation in the text); ends of threads situated under the vocal process (u); ends of threads situated over the vocal process (o) are just being pulled back (p) under the skin through a small skin incision by a Jansen hook [2]

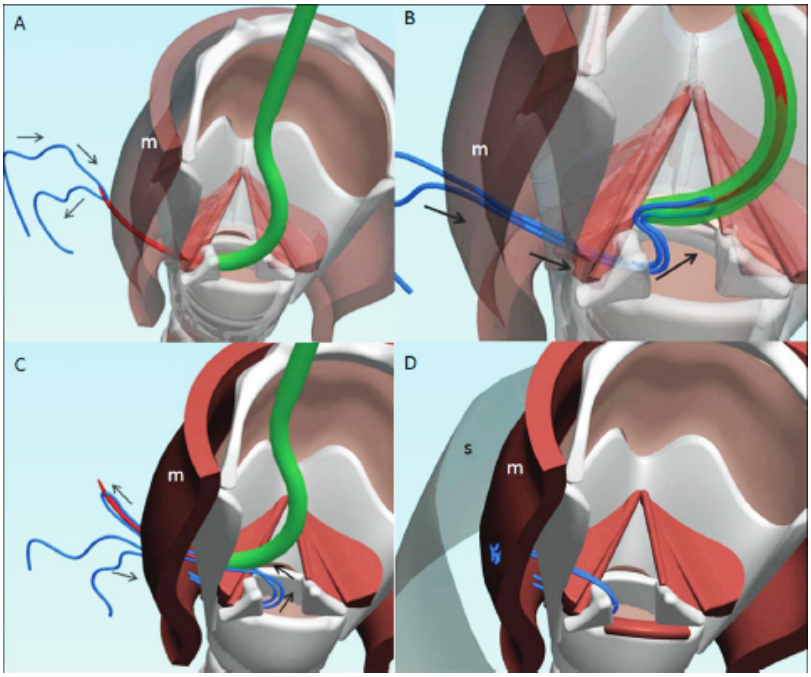

Figure 3: Schematic drawing of the procedure (detailed in the text) [2].

The skin (s) is illustrated only on the last picture to achieve better visualization. Arrows indicate the direction of the thread guiding. m= sternohyoid muscle.

After the disinfection of the mucosa the ETGI is led through the laryngoscope to the glottic level. The mobile (or mobilized) arytenoid cartilage is tilted backward and upward with the end of the instrument (**Fig. 2B**). The built-in, curved blade is then pushed through under the vocal process out to the surface of the neck (**Fig. 3A**). A non-absorbable suture thread (Prolene 1.0; *Ethicon*, Somerville, NJ) is laced through the hole at the tip of the blade by an assistant surgeon (**Fig. 3C and Fig. 3A**). The doubled-over thread is pulled back with the blade, into the laryngeal cavity (**Fig. 3B**).

After a repeated tilting of the arytenoid cartilage (**Fig. 2D**), the blade is pushed out with the thread above the vocal process to the outer surface of the neck (**Fig. 2C**). The assistant surgeon then cuts the double folded thread to remove it from the blade tip. The blade is then pulled back into the laryngeal cavity, and the ETGI can be removed.

A small skin incision (approximately 5 mm) is then created to withdraw the ends of the thread by a Jansen hook to the surface of the sternohyoid muscle (**Fig. 2E**). The corresponding ends are knotted above it (**Fig. 3D**). This simple procedure enables the endoscopic creation of two fixating loops in one step at suitable laryngeal locations, providing maximal physiological abduction of the arytenoid cartilage (**Fig. 2F and Fig. 3D**) within 5 minutes. In case of PGS a topical Mitomycin-C application is considered [8, 38]. In the peri- and postoperative period parenteral antibiotics, steroids for a few days, and speech prohibition for a week are suggested [8]. The suggested hospitalization is about 3 days. The sutures can be removed if recovery is detected at BVCP or in MF after 8 weeks once re-epithelialization in the posterior commissure was confirmed.

1.4. A NEW SOLUTION FOR NEONATAL BILATERAL VOCAL CORD PARALYSIS -ENDOSCOPIC ARYTENOID ABDUCTION LATEROPEXY

In early childhood the possible treatment options for BVCP are much more limited compared to the ones in adulthood. Tracheostomy is the conventional treatment strategy with its well-known challenging care problems, as well as psychological and physical side effects [39-41]. The small anatomical structures, surgery associated post-operative edema and the relatively long and difficult surgical procedures practically exclude the application of both

external approaches and endoscopic resection glottic enlarging procedures. We performed successfully EAAL with the help of pediatric ETGI.

2. AIMS OF THE THESIS

Endolaryngeal Thread Guide Instrument (ETGI, **Fig. 4**) has some standard size parts suitable for all larynges (handle, rod, clamping screw and finger clip) (**Fig. 4a**). However, only stem pipe with the blade has to be introduced into the larynx (**Fig. 4b**). Therefore, intralaryngeal parts, shape and length should be appropriate for allowing precise maneuvers in the larynx, in order to make ideal lateralization suture position over the arytenoid body. Since the size and anatomy of the larynx is different in children and adults, as well as in genders, morphometric analysis of the larynx was necessary for the development of endolayngeal units. The trajectory of the blade goes through the soft tissue of the neck, therefore analysis of the distance between glottic space and skin surface was also important. Moreover, the blade should be capable to penetrate the thyroid cartilage, therefore density of the cartilage was also an important factor for the development ETGI.

Since we did not found detailed size measurements in the literature, development of ETGI, morphometric study of larynx and neck configuration was performed.

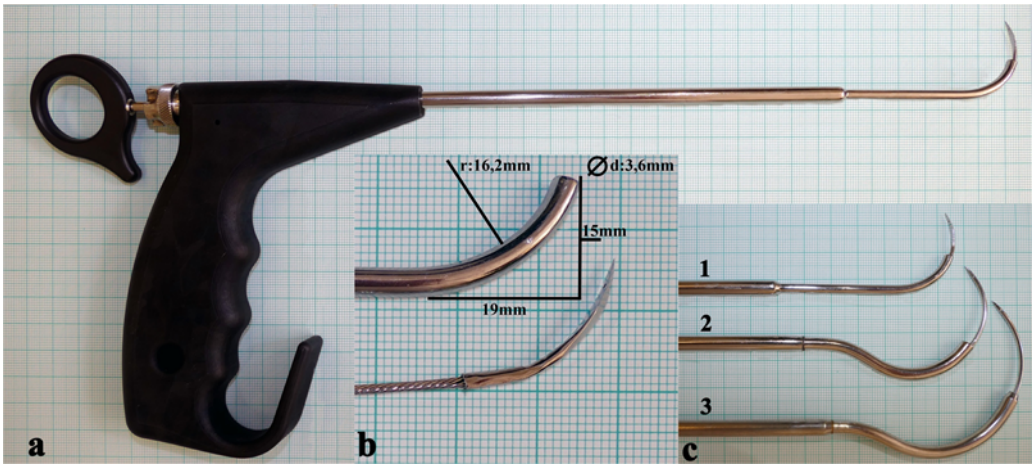

Figure 4: Endolaryngeal Thread Guide Instrument (ETGI)

a) Handling, stem-pipe and curved blade in pushed-out position (stem-pipe and blade designed for infants) b) Stem-pipe and blade designed for infants d: external diameter, r: radius of curvature c) 1. stem-pipe and blade designed for infants; 2. stem-pipe and blade designed for women, 3. stem-pipe and blade designed for men

The aim of our study was to determine human endolaryngeal distances and neck configuration in order to develop intraluminal part of ETGI. We also applied our new instrument in infants with bilateral vocal cord paralysis. Quality of Life Test (QLT) also

applied to verify postoperative results.

1. Morphometric analysis of human larynges - radio-anatomical measurements.
    - Configuration of neck and larynx
    - Analysis of the glottic configuration
    - Analysis of thyroid cartilage density

2. Optimalisation of Endolaryngeal Thread Guide Instrument (ETGI) designed for Endoscopic Arytenoid Abduction Lateropexy (EAAL)
    - Design of adult stem pipe and blades.
    - Design of neonatal stem pipe and blade.

3. The solution of BVCP in infants is really challenging. Endoscopic arytenoid abduction lateropexy proved its efficacy even in these complicated cases.

3. MATERIALS AND METHODS

3.1. MORPHOMETRIC ANALYSIS OF HUMAN LARYNGES - RADIO-ANATOMICAL MEASUREMENTS.

To evaluate human glottic and neck configuration, CT scan of adult and children group were analyzed. All of the CT scans were reported to have normal radiological findings.

3.1.1. Patient selection

In our retrospective study cervical CT scans of caucasian patients who presented for other head and neck complaints to our institute were analyzed. Male and female candidates were randomly selected.

Two groups were created based on the age of the candidates: and (i) adults- above age of 18 (n=93 patient 56 male, 41 female 51±18 year -50±17 year in male group, 54±20 in female group, respectively) and (ii) children -under age of 10 (n=10, 48±15 month).

3.1.2. CT morphometry

Adult group:

Bone and soft tissue filter settings were used to calculate the measurements. The glottic opening was measured using the measuring tool provided on the Picture Archiving and Communication System (PACS) [42] (**Fig. 5A**). To evaluate the configuration of the larynx, glottic space and surrounding anatomical structures and layers (i.e. neck configuration), the following parameters were determined and calculated symmetrically, in both side (mm):

- ***VP-TC*** - The distance from the mucosa of the vocal process to internal lamina of thyroid cartilage.
- ***TC*** - Thickness of thyroid cartilage is the distance between external and internal lamina of thyroid cartilage.
- ***TC-S*** - The distance from external lamina of thyroid cartilage to the surface of skin.
- ***VP-S*** - Summation of the distance of the vocal process to the skin.

Parameters, determines glottic space (mm) (**Fig. 5C**)

- ***AP*** - The anterior to posterior length in the midline.
- ***TM*** - Transverse length at the mid-point of the AP length.
- ***TP*** - transverse length at the level of the vocal process of the arytenoid cartilage.

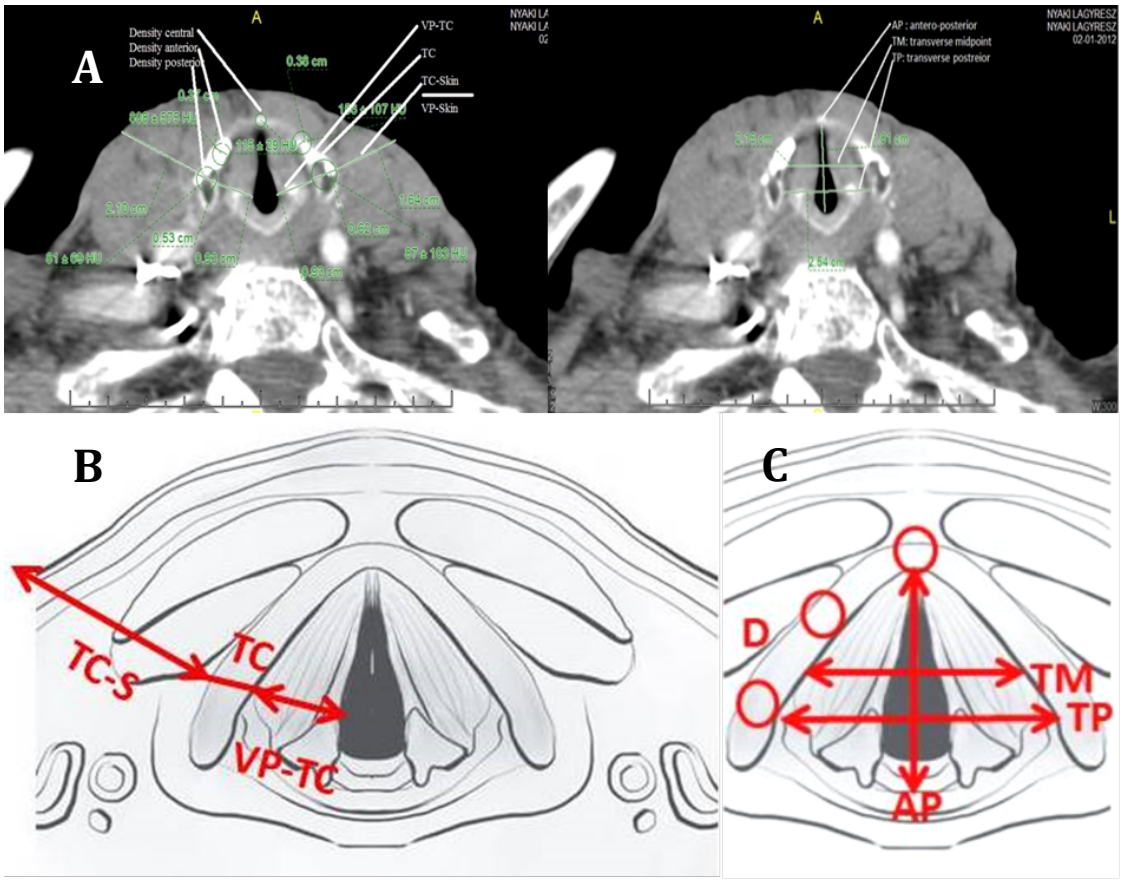

Figure 5: Fig. A: representative images from our study, 54 year old male patient CT scan.

Green and white lines depict calculated distances. Values marked with green numbers, expressed in cm by the program. Fig B,C: Schematic drawing of morphometric parameters, evaluated on CT scans. Picture B: parameters determine neck configuration in mm: VP-TC - The distance from the mucosa of the vocal process to internal lamina of thyroid cartilage; TC - Thickness of thyroid cartilage is the distance between external and internal lamina of thyroid cartilage;- TC-S – The distance from external lamina of thyroid cartilage to the surface of skin. Picture C: parameters, determine glottic space in mm. AP-antero-posterior length in the midline; TM- transverse length at the mid-point of the AP length and TP-transverse length at the level of the vocal process of the arytenoid cartilage. Circles represent area of interests on thyroid cartilage, where density was calculated (i.e. central, anterior and posterior)

To supplement our data, degree of compressibility of the soft tissues of the neck- i.e. tissue layer above thyroid cartilage was also measured on adults. A group of patient, who underwent neck surgery, was selected based on criteria of CT measurements (n=20, 52±17 year). Soft tissue thickness was measured first without compression, with calibrated needle in three different points at the level of vocal folds, both side of the neck. Compression was carried out evenly on the side of the neck and the measurement was repeated. Average compressibility- i.e. difference between thicknesses in mm, before and after compression- was calculated.

To evaluate characteristic of the tissue, density (“”D”, **Fig. 5C**) of the thyroid cartilage was measured at three points: anterior midline- i.e. central, anterior one-third i.e. anterior and posteriorly at the level of vocal process i.e. posterior in Hounsfield units (HFU) [43].

Children group:

Similar parameters calculated in children group, described above. CT scans processed based on the steps as in adult group (**Fig 6**). Small endolaryngeal space allowed only AP and TP distance measurements. Density and compression measurements were not performed.

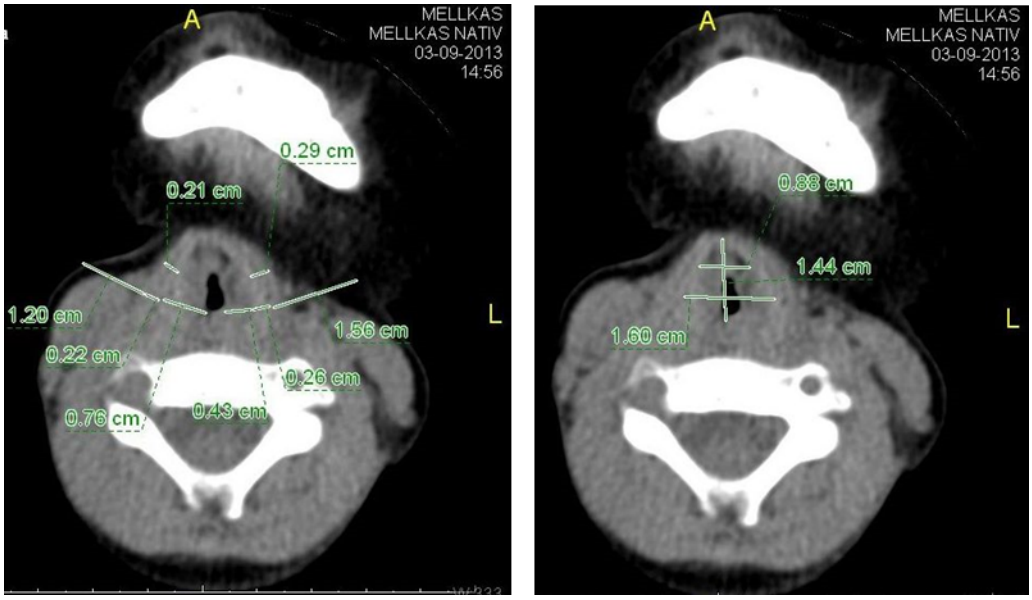

Figure 6: Representative CT image of a 20 month old infant, with measurements points.

3.1.3. Statistics

Statistical analysis was performed with *SigmaStat 4.0 statistical software* (*Systat Software Inc*, California). To test normal distribution of the age in the groups, *Kolmogorov-Smirnov*

Normality Test was performed. The left and right side of the larynx and neck parameters compared with *Student's t-test*. Intergroup significance of male and female group was calculated with ANOVA. Data are expressed in mean ± SD. Level of significance was p=0.001.

3.2. DESIGN OF INTRALARYNGEAL, UNITS OF ENDOLARYNGEAL THREAD GUIDE INSTRUMENT

Based on morphometric analysis, intralaryngeal parts of ETGI i.e. stem pipe and blade were designed. We have to consider, that the size of these parts has to fit the size of the glottic space; it should be appropriate for maneuvers in the glottic space without cause endoluminal trauma, but the blade has to fit for the penetration of the different layers of the neck. Therefore, 3 blade sizes designed, one for infants, and two different sizes for adults. At the planning process of adult blade size, we also considered that soft tissue above the thyroid cartilage can be compressed and therefore blade trajectory can reduce.

3.3. NEW SOLUTION FOR NEONATAL BILATERAL VOCAL CORD PARALYSIS

In the second part of the study, we wanted to prove the advantages of the ETGI, designed for newborns based on previously detailed morphometric CT measurements.
Four newborns with congenital bilateral vocal cord paralysis (BVCP) were chosen as patients. All had been admitted to the perinatal intensive care unit (PICU) immediately after birth due to severe stridor and inspiratory dyspnea. Pregnancy information and patient data are reported in **Table 1**. The complex preoperative examination process included neonatological, neurological, and otolaryngological investigations.

Patient /sex	Gestational age (week)	Delivery	Apgar score	Birth weight (g) /weight-for age percentile	Stridor /Cyanosis	QOL	Intubation (day after birth)	Comorbidity
#1/M	39	SVD	9-7-7	3370/61,7	Y/Y	25	1	-
#2/F	39	caesarean section *(transverse lie)*	7-10-10	3600/78,1	Y/N	25	4	cavum septum pellucidum cyst perinatal infection
#3/F	36	SVD	8-7-7	2210/0,6	Y/N	15	N	prematurity, perinatal infection neonatal hypoglycemia
#4/M	39	caesarean section *(weak contractions)*	7-10-10	3250/51,5	Y/Y	16	N	congenital suprabulbar paresis relative stenosis of the left bronchus

Table 1: Pregnancy information and patient data (SVD: Spontenous Vaginal Delivery, QOL: Quality of Life)

3.3.1. Surgical Technique:

Unilateral, left-sided EAAL was performed in four neonates on the 4th, 5th, 5th and 27th day of life, respectively. All operations were performed under general anesthesia via total intravenous anesthesia and high frequency supraglottic jet ventilation with continuous, strict monitoring of saturation and end-tidal CO2 (ETCO2) and readiness for possible intubation. Jet ventilation was performed by using the *Acutronic* Ams 1000 device (*Acutronic Medical Systems* AG, Hirzel, Switzerland) with the following parameters: inhalation time: 40-50%; frequency: 50-60/min; volume: 200-300 ml; respiratory minute volume 1.2-1.5 l; pressure: 50 mbar. The procedure began with direct endoscopic examination of the upper and lower airways to the level of the distal trachea with a rigid 0° and 30° endoscope. Performance of the EAAL followed immediately afterwards during the same session.

Apart from the size and structural changes of the ETGI, the lateralization of the arytenoid cartilage was performed as described in the introduction.

The total and the endolaryngeal operation time (from the introduction of the ETGI until its final removal) was noted. At the end of the surgery, the babies remained intubated for 3-7

days with an uncuffed tracheal tube (#1,2,4 ID:3,5 mm; #3 ID:3 mm; *Portex*® Siliconised PVC, Oral/Nasal Uncuffed Tracheal Tube; Smiths Medical, MN, USA). The size of ETT was chosen by age- and weight-based formula according to the advice of the anesthesiologist [44].

Parenteral antibiotic (amoxicillin/clavulanic acid, 25 mg/5 mg/kg/12 hours) was administered for 4 days, and methylprednisolone (4 mg/kg) was administered for 7 days. On the day of extubation, the patients were given a steroid bolus. Nasogastric feeding was used in all patients while intubated. The postoperative management took place in the PICU in each case.

4. RESULTS

4.1. MORPHOMETRIC ANALYSIS OF HUMAN LARYNGES - RADIO-ANATOMICAL MEASUREMENTS

4.1.1. Adult group

Age distribution

A total of 107 CT examination, 97 adult (56 males, 41 females) and 10 young children (**Fig. 7**) were performed with an average age of 51±18 year (50±17 year in male group, 54±20 in female group) in the adult and 85±69 month in children group. Considering candidates age, groups showed normal distribution, with p>0.200 in adult group.

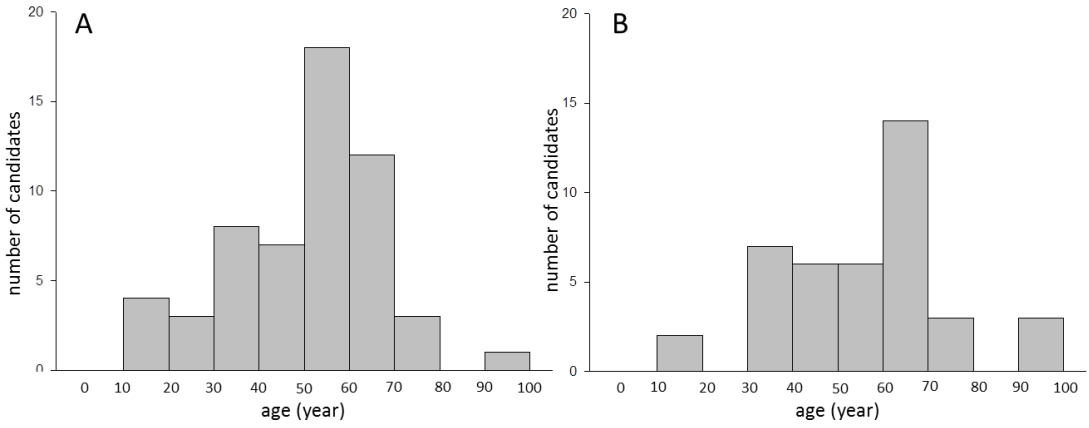

Figure 7: Gender and age distribution of adult group n=97, expressed in years.
Fig 7A: *male group n=56,* ***Fig 7B****:femle group. Age distribution of both sample was normal (p>0.200).*

Configuration of neck

Table 2 shows the determinative distances between anatomical structures and layers in the neck. No significant difference can be proved in the values between left and right side within the male and female group. Comparing the same sides and distances in the two genders, the variables do show a significant difference.

	male		female	
	left	right	left	right
VP-TC	**9.7±1.7**	**9.4±2.0**	8.5±1.5	8.4±1.8
TC	4.8±0.9	4.6±0.8	4.6±1.0	4.7±3.4
TC-Skin	22.2±9.7	21.8±9.1	**24.5±8.2**	**24.0±8.4**
VP-Skin	36.7±1.0	35.7±0.9	37.3±0.9	36.9±0.9

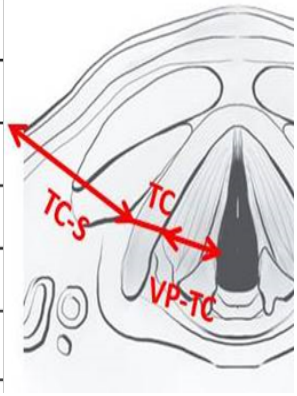

Table 2: Distances between anatomical structures, determinative in the configuration of the neck.
VP-TC*: vocal process-thyroid cartilage distance,* ***TC****: thyroid cartilage thickness,* ***TC-skin:*** *thyroid cartilage-skin surface distance,* ***VP-skin****: vocal process-skin surface distance. Data are represented in mean ±SD mm. No significant difference represented between left and right side. Values labeled with bold character are significantly greater in the given group. p=0.001*

The VP-TC distance in the male group is significantly longer in both sides than the female group (p=0.001). The TC is relatively similar in thickness at the point of trajectory of the blade piercing the cartilage in the female and male groups.

The TC-skin parameter showed the largest difference between the genders, females have significantly thicker soft tissue component as compared to the male group. (p=0.001)

To determine blade trajectory, summation of three above parameters was calculated: (VP-TC)+TC+(TC-skin)=VP-skin. There is no significant difference between male and female group in VP-skin values (**Table 2**). Even though the TC-skin is longer in the female group this is counter-balanced by the VP-TC distance being longer in the male. Since no significant difference between genders was stated, results of groups were integrated, and distribution of TC-Skin distance was investigated. **Figure 8** shows distribution of tissue TC-skin thickness, identical to the trajectory of the blade. Distribution was normal, with a level of significance p>0.200.

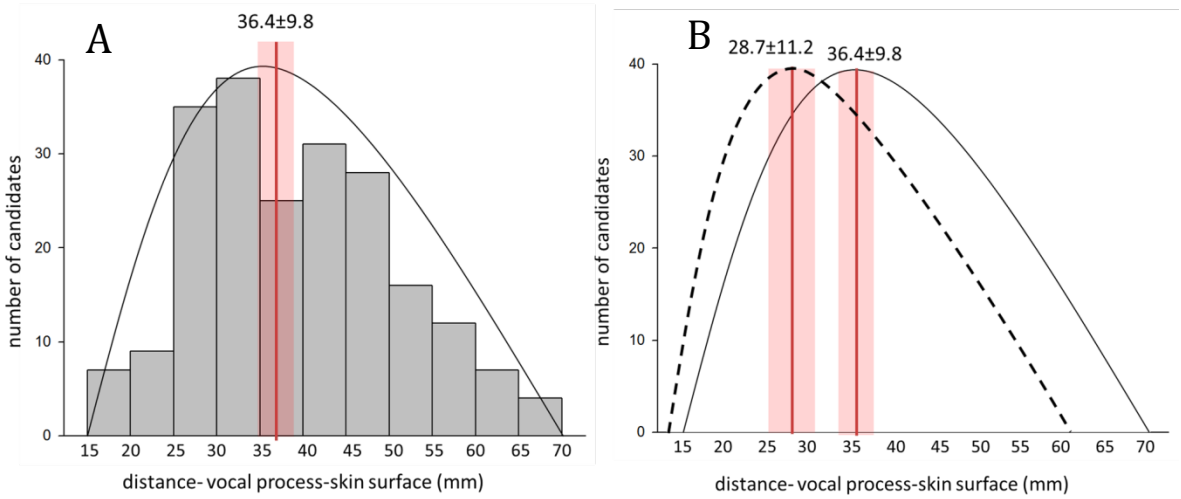

Figure 8: VP-skin thickness i.e. blade trajectory distribution.

Distance represented in mm. Figure 8A: Distribution of the distance is normal in the summarized group (n=97 candidates, p=0.200). Red column represents average thickness (mean±SD). Figure 8B normal distribution and mean±SD of TC-skin thickness represented with simple black line. Dash line represents shift of the distribution to the left i.e which leads to reduced average TC-skin distance.

Compressibility

Since glottic space is relatively small, intraluminal unit should be small enough for the endolaryngeal maneuvers, but has to be long enough to pass through all the anatomical layers. To minimalize necessary size of the instrument, during the lateralization procedure soft tissue layer can be compressed. Compression basically shortens TC-skin distance, therefore VP-skin distance also getting smaller. **Figure 8B** represents how the distribution and average TC-skin distance change after soft tissue compression (without compression 36.4±9.8 mm, with compression 28.7±11.2 mm).

Morphometry of the glottic space

The dimension of the glottic opening in adults is shown in **Figure 9**. Statistically significant differences were found in the three measured length between male and female group; AP 28.2±2.8 mm in male, 24.8±2.5 mm in female group (P= 0.001); TM was 19.7±2.9 in male and 18.6±2.2 mm in female group (P=0.001); TP length was 27.9±4.8 in

male and 20.8±2.6 in female group, (P=0.001). Based on our data, female have significant smaller glottic space compare to male.

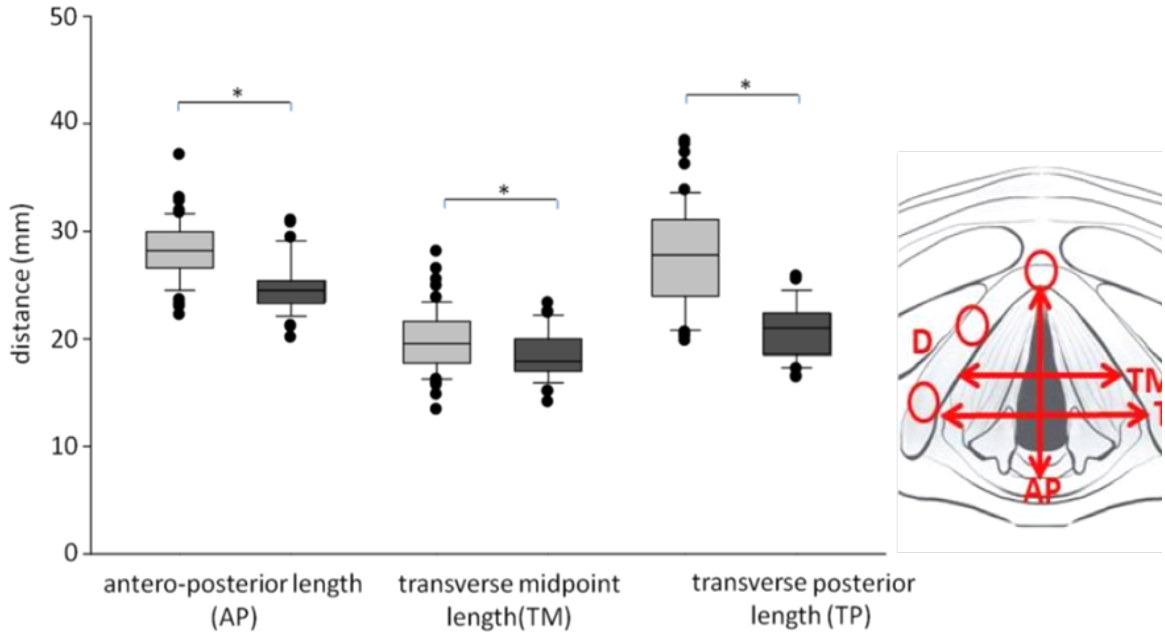

Figure 9: Parameters of the glottic opening: AP-antero-posterior, TM-transverse midpoint and TP-transverse posterior length.

*Data expressed in mm. Light grey boxes represents male, dark boxes represents female group. There is a statistically significant difference between male and female. * Level of significance: p=0.001*

Density measurements

Density of the thyroid cartilage was also determined in the two genders represented in **Figure 10**.

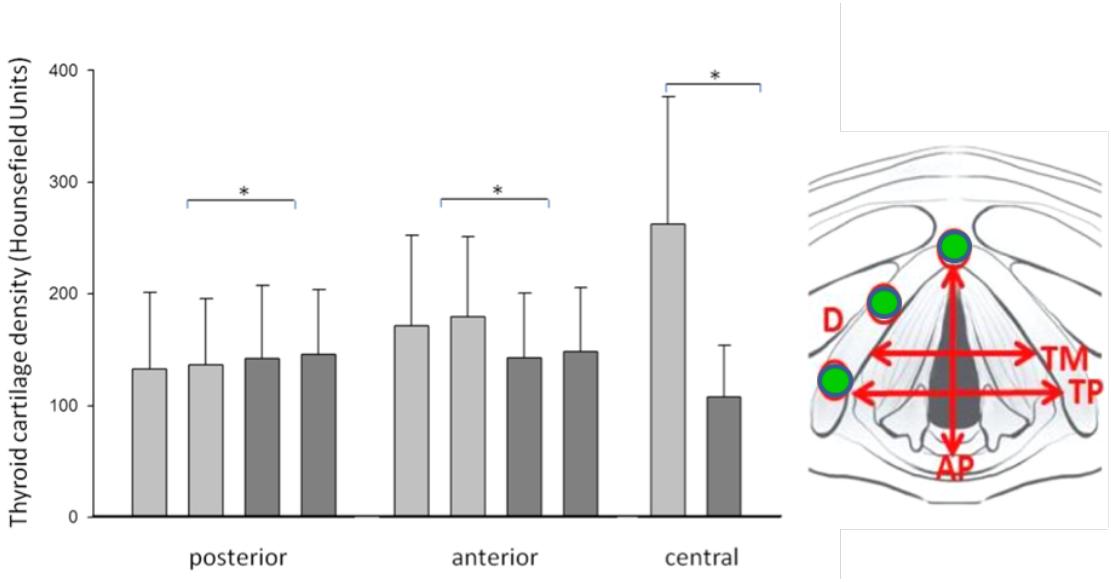

Figure 10: Density of the thyroid cartilage.

Green dots depict the sample sites on the schematic picture. Light grey boxes represent male, dark boxes represents female group, left and right sides. *Level of significance: p=0.001

In the male group, the density was the highest in the midline and decreased posteriorly. The density pattern was different in the female group, central area density was significantly lower compare to male group, and the density of posterior lamina was equivocal. There was no intergroup significant difference between left and right side within the groups. (**Table 3**)

	male		female	
	left	right	left	right
posteior	133±68	137±72	142±65	146±58
anterior	**172±81**	**180±72**	143±58	148±58
central	**236±114**		106±47	

Table 3: Thyroid cartilage density.

Data expressed in Hounsfield units (HFU). Values labeled with bold character are significantly greater in the given group p=0.001

4.1.2. Children group

Since there is no expected difference in sex specific body and organ size in children, especially in infants, male and female candidates created one group.

Configuration of the neck

The thickness of anatomical layers was calculated in a similar way as in adult group. There was no significant difference between the left and right side of the neck. VP-skin thickness showed normal distribution in the group ($p>0.20$). The average TC-skin thickness was 21.3 ±5.5 mm (**Fig. 11).**

	children	
	left	right
VP-TC	6.1±0.5	6.4±0.2
TC	2.3±0.1	2.5±0.1
TC-Skin	11.1±1.5	10.9±1.3
VP-Skin	19.3±3.1	19.4±2.2

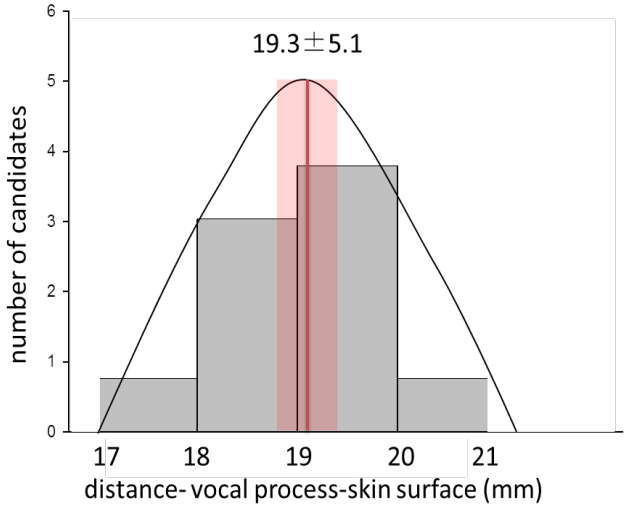

Figure 11: Distances between anatomical structures, determinative in the configuration of the neck/ distribution of VP-skin distance.

No statistical significant difference can be found between left and right side. TC-skin distance performed normal distribution in the group.

Morphometry of the glottic space

Based on CT scans, average AP length was 18.8±4.6 mm and TP was 20.5±4.2 mm in the group (**Fig. 12**) .

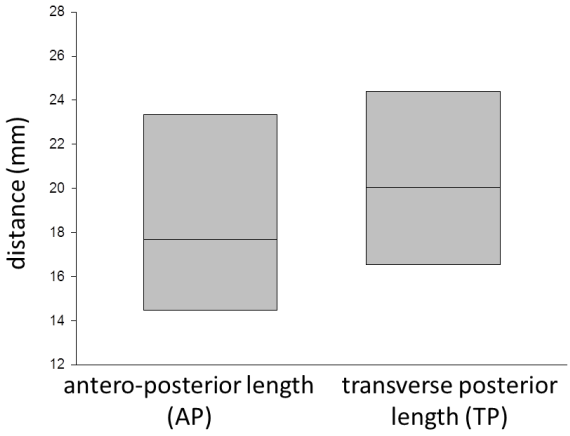

Figure 12: Antero-posterior (AP) and transverse posterior (TP) length in mm

4.2. DESIGN OF THE INTRALARYNGEAL UNITS OF ENDOLARYNGEAL THREAD GUIDE INSTRUMENT

At the design of the instrument, the following parameters had to be considered:

(i) Thickness of laryngeal and neck structures- distance between vocal process to the skin - blade should be enough long for penetration (i.e. necessary length)

(ii) Glottic space- limitation factor of the size of stem pipe and blade

(iii) Density of the cartilage- the most compact layer of the neck should be penetrated by the balde

To determine necessary length of the ETGI blades, neck configuration should be considered.

In adult group, based on VP-skin distance i.e. thickness which should be penetrated, we applied a 41 mm blade. This length calculated to be long enough in more than 50% of the cases. A longer, 55 mm blade was also prepared which is capable for lateralization procedure more than 90% of the cases. Longer blade size was not necessary, since soft tissue compression can reduce blade trajectory. Re-calculate VP-skin distance with soft tissue compression, 90% of the cases can be solved with 41 and 99% with 55 mm blade (**Fig. 13**).

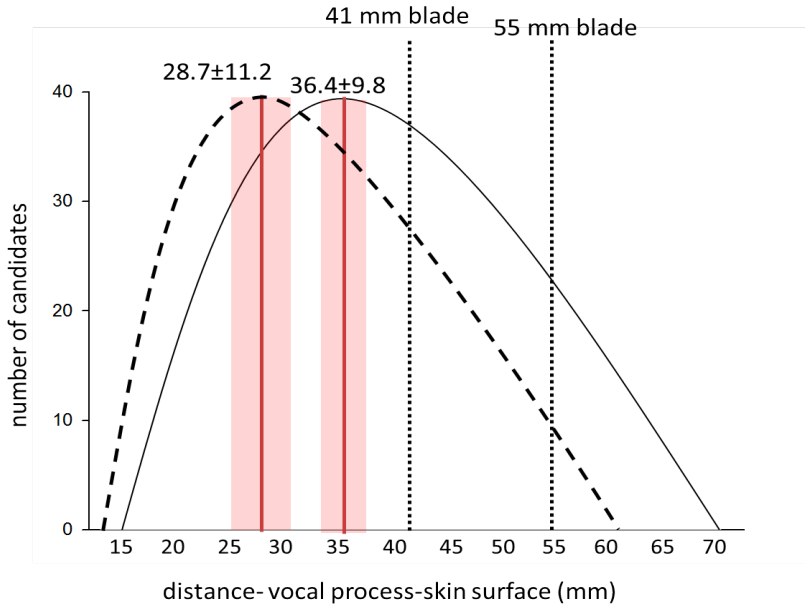

Figure 13: Diagram represents distribution of tissue thickness i.e. distance between the surface mucosa of vocal process to skin surface in adult group.

Black lined curve indicates thickness distribution without compression of surface soft tissue. External compression of surface soft tissue shifts the distribution to the left (dash line curve) and reduces average tissue thickness, marked with red line and box (mean ±SD). Length of the different blades represented with dotted line. With tissue compression, 90% of the cases can be solved with 41 and 99% with 55 mm blade. (Without compression this ratio is 69% with 41mm and 94% respectively.)

During the planning process, we had to consider, that male glottic space and distances are significantly larger than those in female glottis. However, rotation of the instrument helps the introduction of the stem-pipe and blade into the correct position, curvature of the blade should be modified based on the measured endolaryngeal distances. During the blade penetration, the angle between the instrument and the mucosa surface is 45°, and the level of the vocal fold is in the center of the blade (i.e. midline), bisector should not be longer than the determined transverse glottic distances (i.e. TM: 19.7±2.9 in male and 18.6±2.2 mm in female; and TP: 27.9±4.8 in male and 20.8±2.6 in female). Based on CT measurements, the TM length is the critical value of the atraumatic introduction of the device; therefore the bisector length (i.e. the width of the territory occupied by the blade in the glottic area) should not exceed the TM. **Figure 14** shows the shape of the two blades, based on this concept. Bisector length (**Fig. 14**) of 55mm blade (b_1=13mm) and 41 mm blade (b_2=7mm) are suitable in all of the cases.

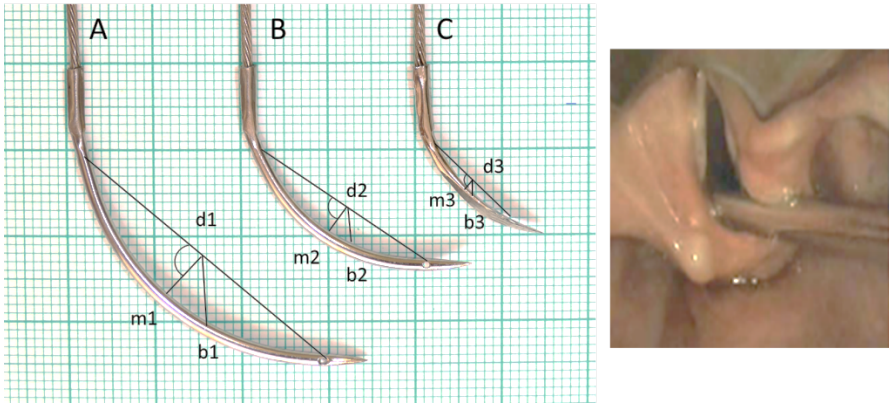

Figure 14: Shape of ETGI blades; A-55 mm curvature, B-41 mm curvature C-21mm curvature length.
Inner distance represented with letter "d". Letter "b": bisector length, proportional of the width, necessary for atraumatic introduction of the device. Bisector lengths are shorter, than critical transverse length of the glottis. Intraoperative picture shows, that angle between surface mucosa and the instrument is ~ 45°.

Density of thyroid cartilage, VP-skin and TM determine the size of the blade used. Therefore massive, longer blade is necessary for male patients. However, sharp edged blade is better for penetration, but the risk of possible tissue and vessel trauma is higher. Therefore we applied blade with blunt edge.

In children, small glottic size and the thin soft tissue layer over the larynx requires a shorter and less curved endolaryngeal portion of the stem-pipe as opposed to the curve of the adult sized device. Especially in newborn, small glottic area (AP 18.8±4.6 mm, TP 20.5±4.2 mm) significantly reduces possible size and shape of the blade. We applied a 21mm curvature length bade, suitable in 100% of the cases (**Fig. 15**). Bisector length (**Fig. 14**) of 21mm blade, created for children is b_4=2.1 mm.

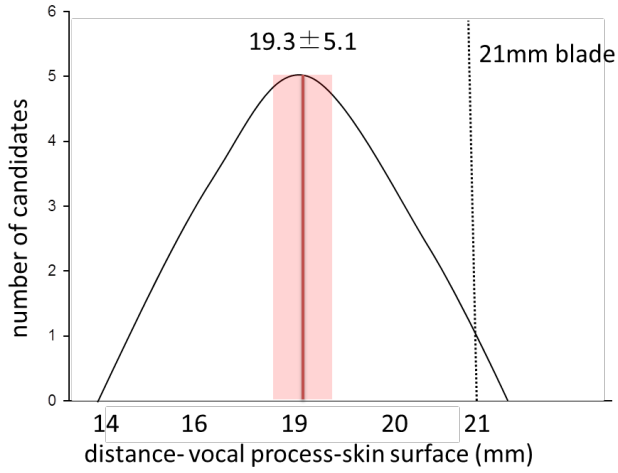

Figure 15: Diagram represents distribution of tissue thickness i.e. distance between the surface mucosa of vocal process to skin surface in children group.

Average tissue thickness marked with red line and box (mean ±SD). The blade, designed for children is 21 mm.

4.3. NEW SOLUTION FOR NEONATAL BILATERAL VOCAL CORD PARALYSIS- ENDOSCOPIC ARYTENOID ABDUCTION LATEROPEXY

The mean total surgical time was 17 minutes, with an average of 6 minutes spent on the endolaryngeal lateralization. No major perioperative or postoperative complications occurred. The postoperative time line of events is presented in **Table 4**.

Patient /sex	EAAL (days after birth)	Endolaryngeal Surgical Time (min)	Postoperative Complication	Extubation (postoperative day)	Reintubation (postoperative day)	Oral Feeding (postoperative day)
#1/M	4th	6	N	5th	N	7th
#2/F	5th	5	laryngeal edema	7th	26th-32th	10th
#3/F	5th	8	N	3th	N	4th
#4/M	27th	6	N	7th	N	9th

Table 4: Details of the surgery and events of the postoperative care (EAAL: Endoscopic Arytenoid Abduction Lateropexy).

Abbreviations: M-male, F-female, N-no

Extubation was considered safe on the 5th, 7th, 3th and 7th postoperative day, respectively. In the case of infant #2, extubation was attempted on the 4th postoperative day; but due to

significant edema of the laryngeal mucosa, the intubation had to be prolonged by 3 days. Dyspnea and CO2 retention presented were noted on the 26th postoperative day. Direct endoscopic examination revealed severe edema of the glottic soft tissues. Thus, reintubation and repeated antibiotics were required for another 6 days. All patients were able to tolerate a normal per os diet with no restriction in 1-3 days post extubation. The weight-for-age and length-for-age percentiles are depicted in **Figure 16**.

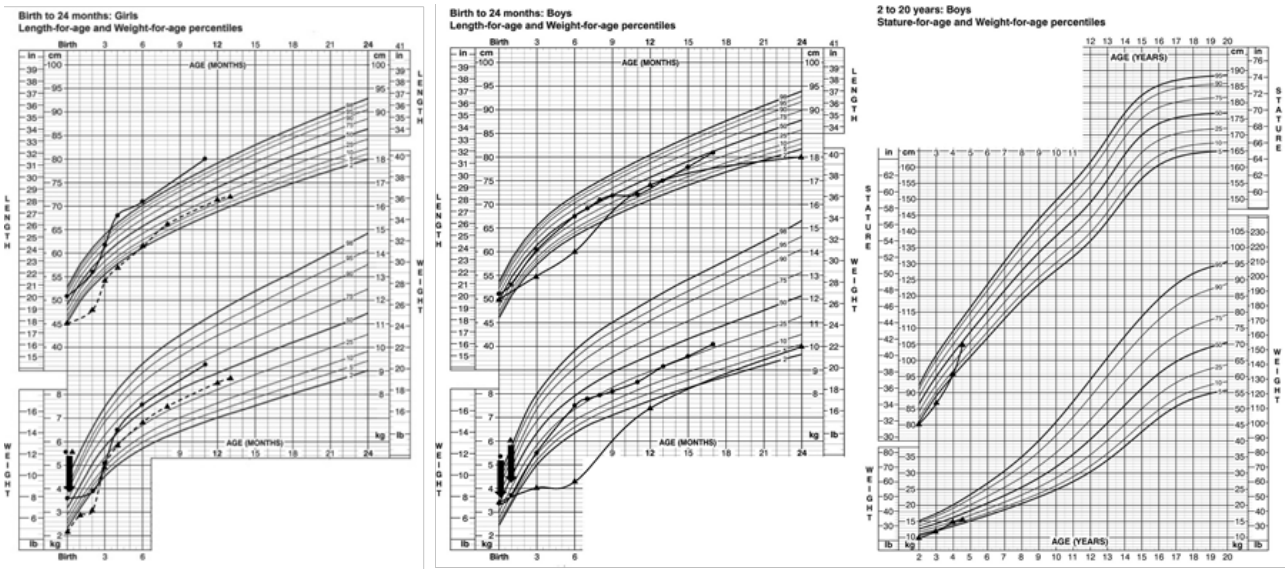

Figure 16: Length-for-age and weight-for-age percentiles of the patients.

Length-for-age and weight-for-age percentiles of patient #2 and #3 dot: patient #2, triangle: patient #3, arrow: day of the surgery Length-for-age and weight-for-age percentiles of patient #1 and #4 dot:patient#1, triangle:patient#4, arrow: day of the surgery.

The acoustic parameters, QOL scores, and the characterization of vocal cord movement recovery are shown in **Table 5**.

Patient	Jitter [%]	Shimmer [%]	HNR [dB]	Mean Pitch [Hz]	QOL	Vocal cord movements	Follow up [month]
#1/M	0.3	5.4	15.9	171.7	11	N	17
#2/F	5.9	20.1	3.5	261.1	8	R: complete abduction and adduction L: slight adduction	11
#3/F	0.4	4.6	16.4	360.4	7	R: complete abduction and adduction	13
#4/M	1.3	4.7	18.5	328.0	6	N	55

Table 5: Functional outcomes of the surgery

Abbreviations: HNR: harmonic to noise ratio; QOL: Quality of Life; R: right side, L: left side, N: no movement

Compared to the preoperative values, the QOL scores improved significantly in all cases. Based on the parent's observations, the voice of the patients was normal in 3 cases and slightly impaired in 1 case. In the first three patients, the crying sounds were powerful. Gurgling and cooing were similar to their siblings, according to the parents. Speech development was appropriate in the fourth case, which was the only case followed long enough (55 months) to be able to evaluate it adequately. Partial regeneration of the vocal cord movements was observed in 2 of the 4 cases: bilateral in infant #2 and unilateral in #3, at 6 and 3 weeks of age respectively (**Fig. 17**). Lateralization sutures were not removed in any of the cases.

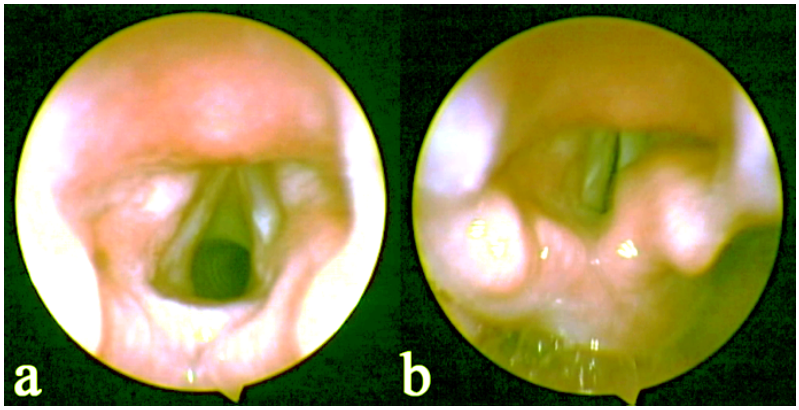

Figure. 17: Intraoperative images.

Complete regeneration of the right vocal cord movements after left-sided endoscopic arytenoid abduction lateropexy (patient #3, 3rd postoperative week)

5. DISCUSSION

Endoscopic arytenoid abduction lateropexy (EAAL) has already been shown to be safe and effective for the treatment of vocal cord immobility of various etiologies [2, 4, 8]. To create an instrument, capable to perform the intervention in minimal invasive way, neck and laryngeal conformation should be studied first. We wanted to design intralaryngeal units of ETGI- prepared for manipulation in glottic space and penetration of the tissue layers- suitable for different glottic size and neck configuration. Resistance of the most compact layer i.e. density of the thyroid cartilage have also been taken into consideration. In the first part of the thesis, a retrospective morphometric study of the human larynx was detailed. Based on these findings, design of intralaryngeal ETGI units was demonstrated. Considering the conformation differences between genders, adults and infants; three different blades have been created.

Minimal invasive treatment of BVCP is an important question especially in childhood. EAAL is a good solution even in infants to avoid tracheotomy and consequent, long term structural and functional damage of the larynx. In the second part of the thesis, we demonstrated the advantages of our minimal invasive method with ETGI, designed for children.

5.1. Morphometric analysis of human laryngeal images for optimization of suture lateralization instruments

We analyzed a large series of cervical CT scans of 56 males and 41 females and 10 children (total of 107) which examined the anatomy of the larynx. We found a gender difference between the layers of the neck: VP-TC distance, which represents the mucosa and vocal fold thickness was significantly longer in male. While neck soft tissue thickness i.e. distance between thyroid cartilage and the surface (TC-skin) was longer in females. This difference might be due to the fact that male larynx is in a more anterior position generally compared to the female larynx position or fat distribution is different in the neck according to gender.

No gender difference was presented in average cross section of neck soft tissues (VP-skin), moreover, it showed normal distribution. Based on VP-skin distance, which is identical with

blade trajectory, two different adult ETGI blade lengths have been designed. With the 41 mm curvature length blade, 50%; with the 55 mm curvature length, 90% of the cases could have been solved. We have also proved that application of longer blades is not necessary; with soft tissue compression of the neck, cross-section can be reduced adequately, and even with the 41 mm blade 90% of the cases could be treated. Moreover, limited space in the level of the vocal cord also requires shorter blade length.

Endolaryngeal space measurements showed, that female glottis is significantly smaller in sagittal as well as in transversal diameter than male ones. To avoid spatial incompatibility, blades were designed to have a round caliber. Moreover, round shape also provides ideal penetration angle for soft tissue and cartilage, and gives enough rigidity to resist bending. To determine the curvature, middle and posterior transverse diameters i.e. TM and TP were calculated. Since the instrument and also the tip of the blade meets the surface of the mucosa with 45°, we designed bisector length (proportional with the width occupied by the blade in the glottic area) shorter, than transverse glottic length.

The laryngeal cartilages are hyaline cartilages, except for the epiglottis and the vocal process of the arytenoid, which are fibroelastic cartilages [45, 46]. Hyaline cartilages undergo certain structural changes with time, like progressive enchondrial ossification [47]. Histopathological studies have demonstrated that the stage of the calcification and ossification is widely affected by age [48]. Male laryngeal cartilages tend to be ossified to a greater extent than female cartilages [45, 47, 49-54]. Ossification increases with advancing age [47, 50, 52-56]. For both genders, thyroid cartilage ossification appeared to pass through different phases until complete ossification, and each phase appeared to be correlated to a decade [47-49]. Determination of cartilage density was also necessary to create ETGI blades resistant enough. Moreover, density distribution also influences the site of blade penetration. We found a gender difference between thyroid cartilage densities at all measured level. However, the cartilage thickness increases posteriorly; density measurement showed that the posterior third is less compact. This might be due to the structure of the cartilage; there is a compact surface lamina, conjugating in the middle and anterior third (identical with the sample site of anterior density measurement), while posteriorly a spongious intermediate substance can be found (posterior sample site). However, cartilage is thinner anteriorly, our density measurements have confirmed, that posterior part of the cartilage is more sufficient for penetration.

Moreover, calcification usually affects the anterior part of the lamina, therefore here density, and consequent resistance increases with time. At the beginning, lateralization of vocal cord was performed anteriorly, since intralaryngeal units of previous instruments were not capable to penetrate the thick posterior part of the cartilage. We recommend blade penetration at the posterior part of the lamina based on the density measurements; moreover, this position secures the maximal abduction of the vocal cord. Since the density of cartilage is higher in males, we also recommend the application of 55 mm blade in these cases, to utilize higher instrument resistance provided by the size of the blade.

The small glottic area of newborns made the use of the original endolaryngeal thread guide instrument (ETGI) difficult, so it had to be modified [57]. First step was the miniaturization of the instrument to make it easier to maneuver in the neonatal glottis. The small glottic size and the thin soft tissue layer over the larynx requires a shorter and less curved endolaryngeal portion of the pipe-stem as opposed to the curve of the adult sized device. For children, a 21mm curvature length blade has been designed, capable to perform EAAL in 100% of the cases. Since superficial soft tissue (i.e. tissue above thyroid cartilage) in children, especially in infants is thin, soft tissue compression is not optimal to reduce cross-section. Therefore, application of a 21 mm blade was necessary. The second step was the conversion to the neonatal *Miller* laryngoscope (size 0; *Welch Allyn* Inc., NY, USA) which provides a good view for the lateralization of the left arytenoid cartilage (in three cases). In the last patient, a *Macintosh* Baby Laryngoscope (*Welch Allyn* Inc., NY, USA) was used to expose the larynx.

However, sharp edged blade is better for penetration, but the risk of possible tissue and vessel trauma is higher. Therefore we applied a blade with blunt edge. In order not to weaken the tip of the blade the eyelet was placed proximal to the tip.

Since there are a number of factors, which have to be taken into consideration when performing the EAAL procedure, a cervical neck CT is a helpful investigation in the pre-planning stage. Since imaging is usually performed in order to find the cause of vocal cord immobility, patients do not receive any extra radiation.

The results of the scan will help to clarify the degree of ossification of the TC at the vocal process level, the distance of the blade trajectory and the thickness of the neck.

5.2. New Solution for Neonatal Bilateral Vocal Cord Paralysis - Endoscopic Arytenoid Abduction Lateropexy

Due to the many etiologies of bilateral vocal cord palsy (BVCP), the potential comorbidities, the related anatomical abnormalities, and the complex requirements of the treatment, many authors recommend a "watch and wait policy" in neonates [58]. However, the associated airway limitations significantly limit the normal physical activity and development of the child, even in milder cases [59]. In cases of severe dyspnea, tracheotomy is still the most frequently performed surgical intervention despite its many well-known risks, including severe complications such as airway stenosis and accidental decannulation which can be life threatening [39-41, 60]. The need to minimize surgery in the neonate and the many risks of neonatal anesthesia (small reserve capacity, high oxygen requirements, risk of hypothermia and hyperthermia, undiagnosed heart problems, limited cardiac output, etc.) make surgical options even more limited in this age group. The optimal surgical intervention would be both quick and reversible as well as provide an immediate adequate airway, acceptable voice quality, and good swallowing function. A simple suture lateralization technique of the vocal cord from an external approach was introduced by *Zawadzka-Głos* in children aged 1 year and older [61], but this technique did not become popular. *Triglia et al*. applied the arytenoid lateropexy from an external approach on 15 children between 1 month and 9 years with more encouraging results; however, the undertaking of this relatively complex and long-lasting intervention is significant in neonates. Because of the extensive, surgical dissection of the arytenoid region and the resulting scar formation, this procedure is considered to be irreversible even on adults [62-65].

Our preliminary results show that the endoscopic arytenoid abduction lateropexy (EAAL) can be relatively easily and quickly performed with low surgical stress even in the first days of life. Moreover, it provides a stable, long-lasting, and wide airway that is potentially reversible because the endoscopically inserted lateralization sutures do not significantly

disturb the anatomical structures. This has been proven in several adult cases in which definite re-innervation occurred [2, 4, 44, 66, 67].

The supraglottic jet ventilation and the novel use of pediatric laryngoscopes ensure excellent visualization of the glottis with access unencumbered by an endotracheal tube. If jet ventilation is not available, however, this fast procedure can be performed under spontaneous ventilation with intermittent intubation [2]. Based on our experience, the new, modified endoscopic thread guide instrument (ETGI) is suitable for fast and safe maneuvering in the narrow laryngeal space of the newborns.

The blade is connected with the stem-pipe. Continuously, thus the device can be removed promptly in case of the need for intubation. Visual control during the technique is paramount. Moreover, the positioning of the lateralization suture can be made more precisely with endoscopic guidance. With these associated technologies and instrumentation, the procedure can be performed quickly and safely.

This intrinsically reduces the potential complications from anesthesia and jet ventilation. In adult patients, no postoperative intubation, temporary tracheostomy, or intensive care are required after EAAL. Due to the limited anatomical space, the increased vulnerability, and swelling of the soft tissue of the neonates, a short-term postoperative intubation is always prudent along with parenteral steroid therapy. Temporary intubation may also help by the maintaining of the lateralized position of the arytenoid cartilage though our report did not compare this to any cases that were immediately extubated. Perioperative empiric intravenous antibiotic therapy is also indicated.

The presented lateralization technique does not impair laryngeal sensation, which is essential for protective laryngeal reflexes [68]. This is consistent with our experience in adult patients who have not had significant aspiration after arytenoid cartilage lateralization. After the removal of the nasogastric feeding tube, the newborns in this series could be easily fed and be nurtured. This is supported by parental reports and by the registered weight gain and length growth. Despite the comorbidities and the long hospitalizations, the weight-for-age and length-for-age percentiles show normalization after the initial growth delay. The objective measurements of voice quality are very limited at this age, but the results of the voice analysis are consistent with the QOL questionnaire’s results. The postoperative glottic configuration of

a small angle in the anterior commissure and the straight and tensed vocal cords allows acceptable phonation closure in case of contralateral vocal cord recovery [4, 69]. This allows not only a voice improvement after spontaneous re-innervation, as was seen in the second and third case, but it helps to maintain the airway patency. This procedure is reversible in adults, and therefore likely reversible in children. However, we did not undertake any reversal on the infants during this study period. Reversal needs to be carefully considered because re-innervation of the two vocal cords does not necessarily occur simultaneously. We have observed in adults that when reversal is undertaken because the contralateral vocal cord's movement has recovered, the released (but potentially still paralyzed) vocal cord can re-medialize after the suture removal [6]. While that is acceptable in an adult, in the young and very small larynx this medialisation might cause a significant increase in airway resistance. As the unilateral lateralization suture does not cause any swallowing or phonation impairment, it was not removed after partial functional recovery. This was in accord with the parent's decision. The suture removal can be considered in the future if the endoscopic and/or LEMG examinations confirm the re-innervations or when the larynx has grown larger.

Endoscopic examinations proved the stable position of the lateralization sutures and the abducted arytenoid cartilage after 4 years in the one patient that we followed for that long. This surgical intervention might be a long-term solution, even in fast-growing laryngeal structures

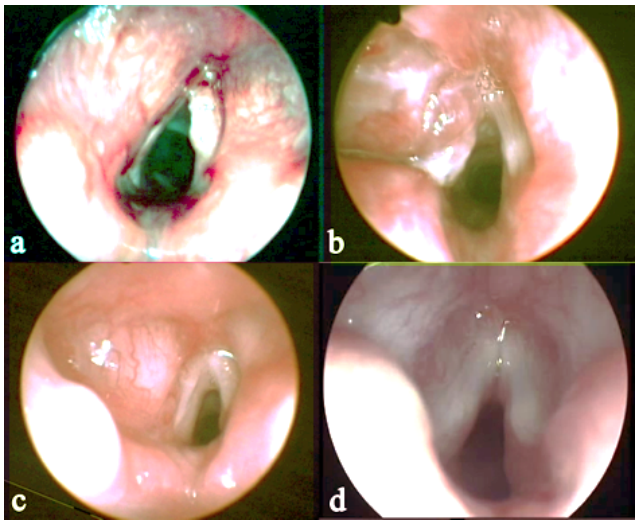

Figure 18: Endoscopic pictures of the lateralized left vocal cord

a) Patient #1 (3rd postoperative week), b) Patient #2 (2nd postoperative week), c) Patient #3 (2nd postoperative month), d) Patient #4 (4th postoperative year)

6. CONCLUSIONS AND NEW RESULTS

6.1 Morphometric analysis of human laryngeal images

This study showed that the glottis configuration is significantly different between the two genders. The density at the post lamina of the thyroid at the level of the vocal process of the arytenoid is not significantly different in the two genders. The soft tissue compressibility allowed the shorter blade to be used in the majority of cases giving greater flexibility. However considering the size of larynx, maneuverability of instrument and density of thyroid cartilage the larger blade was advised to be used for greater success. CT evaluation of cervical neck and the above measurements described will provide the preoperative planning for choosing the required type of blade to be used.

6.2 Optimalisation of Endolaryngeal Thread Guide Instrument (ETGI) designed for Endoscopic Arytenoid Abduction Lateropexy (EAAL)

EAAL as a primary treatment might serve as a minimally invasive, effective, dynamic solution for most cases of BVCI. ETGI is specifically designed for this method; therefore it can facilitate this procedure. With blades and stem pipes of different shapes and sizes the operation can be carried out in the case of almost every laryngeal configuration.

6.3 A New Solution for Neonatal Bilateral Vocal Cord Paralysis - Endoscopic Arytenoid Abduction Lateropexy

According to our preliminary results, the minimally invasive, quick, reversible endoscopic arytenoid abduction lateropexy (EAAL) might be a more favorable solution for neonatal bilateral vocal cord paralysis (BVCP) than earlier treatment strategies. In one step, the airway can be maintained without the risk of any permanent damage to voice production. Good swallowing function is also preserved. In addition to these benefits, it should be easily reversible. The specially modified endolaryngeal thread guide instrument (ETGI) gives a fast and effective option to create the lateralized arytenoid position even in this technically challenging surgical field of a neonate larynx.

Follow up long-term outcomes and additional patients need to be studied to further validate this procedure.

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9. ATTACHMENT

MAGYAR SZABADALMI HIVATAL

HASZNÁLATI MINTAOLTALMI OKIRAT

A Magyar Szabadalmi Hivatal az okirathoz fűzött leírás alapján

3 413

lajstromszámon az U 07 00163 ügyszámú bejelentésre használati mintaoltalmat adott.

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A mintaoltalom jogosultja és feltaláló:

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dr. Madani Shahram, Szeged	23%
dr. Jóri József, Szeged	3%
Szekeres László, Szeged	23%

Budapest, 2008. március 5.

Dr. Bendzsel Miklós
elnök

Modification of inventors in ETGI's patent document in 2009:

Szabadalmi Közlöny és Védjegyértesítő – 114. évfolyam 5. szám II. kötet, *2009.05.28.*
Vegyes használati mintaoltalmi közlemények

Vegyes használati mintaoltalmi közlemények

Jogutódlás **PC3K**

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A rovat 1 db közlést tartalmaz.

I.

The Laryngoscope

A New Solution for Neonatal Bilateral Vocal Cord Paralysis: Endoscopic Arytenoid Abduction Lateropexy

Shahram Madani, MD; Ádám Bach, MD; Vera Matievics, MD; Eszter Erdélyi, MD; Balázs Sztanó, MD, PhD; Ilona Szegesdi, MD; Paul F. Castellanos, MD, FCCP; László Rovó, MD, PhD

Objectives/Hypothesis: Bilateral vocal cord paralysis in early childhood is a life-threatening condition, which often requires immediate intervention. One of the treatment options is a quick, reversible simple suture vocal cord lateralizing technique, whereby the arytenoid cartilage is directly lateralized to the normal abducted position. Considering pediatric laryngeal anatomy, a small endolaryngeal thread guide instrument was designed for precise suture insertion.

Study Design: New instrument validation.

Methods: Four newborns had inspiratory stridor immediately after birth; two had to be intubated. Laryngotracheoscopy revealed bilateral vocal cord paralysis. Unilateral, left-sided endoscopic arytenoid abduction lateropexy was performed with supraglottic jet ventilation on the 4th, 5th, 5th, and 27th day of life for the four patients, respectively.

Results: All babies remained intubated for 3 to 7 days with an uncuffed tracheal tube. After extubation, no dyspnea or swallowing disorder occurred. A subjective quality of life questionnaire, laryngotracheoscopy, clinical growth charts, and voice analysis showed satisfactory functional results.

Conclusions: Minimally invasive, quick, reversible endoscopic arytenoid abduction lateropexy might be a more favorable solution for neonatal bilateral vocal cord paralysis than earlier treatment strategies. In one step, the airway can be maintained without the risk of any permanent damage to voice production. Good swallowing function is also preserved. The specially modified endolaryngeal thread guide instrument gives a fast and effective option for creating the lateralized arytenoid position even in the technically challenging surgical context of a neonate larynx.

Key Words: Bilateral vocal fold paralysis, dyspnea, endolaryngeal thread guide instrument, endoscopic arytenoid abduction lateropexy, laterofixation, neonatal.

Level of Evidence: 4.

***Laryngoscope*, 00:000–000, 2016**

INTRODUCTION

The treatment of bilateral vocal cord paralysis is a challenge in children, especially in neonates. This phenomenon has multiple etiologies. These include iatrogenic, neurological, idiopathic, joint fixation, and birth trauma. Idiopathic paralysis is the most common, but a neurological origin is presumable in those cases as well.[1] According to the literature, two-thirds of paralytic patients have shown some or even total recovery.[2–4] Thus, due to the heterogeneity of the pathology, each case needs to be assessed on its own merit as to whether long-term improvement is possible. Associated stridor and respiratory distress, however, generally require urgent interventions because the "watch and wait" policy may lead to a dire outcome, considering the tiny airways of babies.[5] The possible treatment options in neonates are much more limited compared those in adulthood. This is because achievable airway improvement with classic resection procedures (such as partial/total arytenoidectomy or transverse cordotomy) is limited by the associated edema, which often makes a tracheostomy necessary.[6] Despite the high spontaneous recovery rate after a short period of oxygen hood therapy or intubation, in most cases, tracheostomy is the conventional treatment strategy, with its well-known challenging care problems, as well as psychological and physical side effects.[4,7,8]

Our recent publication objectively proved, in accordance with the clinical observations, that of the popular glottis-enlarging surgeries, those procedures that are based on the natural abduction of the cricoarytenoid joint(s) are the most effective in airway improvement.[9–12] Moreover, these "simple suture procedures" are reversible, which makes the abovementioned decision making easier. The problems that arise with these arytenoid lateropexies in this age group are obvious; the small anatomical structures and the relatively long and difficult surgical procedures practically exclude the application of the external approaches. The faster and simpler endoscopic procedure described by our team is

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TABLE I.
Pregnancy Information and Patient Data.

Patient/Sex	Gestational Age, wk	Delivery	Apgar Score	Birth Weight, g/Weight-for-Age Percentile	Stridor/ Cyanosis	QOL	Intubation, Days After Birth	Comorbidity
#1/M	39	SVD	9-7-7	3,370/61.7	Y/Y	25	1	—
#2/F	39	Caesarean section (transverse lie)	7-10-10	3,600/78.1	Y/N	25	4	Cavum septum pellucidum cyst, perinatal infection
#3/F	36	SVD	8-7-7	2,210/0.6	Y/N	15	N	Prematurity, perinatal infection, neonatal hypoglycemia
#4/M	39	Caesarean section (weak contractions)	7-10-10	3,250/51.5	Y/Y	16	N	Congenital suprabulbar paresis, relative stenosis of the left bronchus

F = female; M = male; N = no; QOL = quality of life score; SVD = spontaneous vaginal delivery; Y = yes.

also challenging, considering that the endolaryngeal thread guide instrument (ETGI; Mega Kft, Szeged, Hungary) was designed for adults and not such a small glottic area. To alleviate this problem, a prototype of a new commutable blade and stem-pipe was designed so that the original instrument could be used in the neonatal airway.

MATERIALS AND METHODS

Patients

Four newborns with congenital bilateral vocal cord paralysis (BVCP) were chosen as patients. All had been admitted to the perinatal intensive care unit (PICU) immediately after birth due to severe stridor and inspiratory dyspnea. Pregnancy information and patient data are reported in Table I. The complex preoperative examination process included neonatological, neurological, and otolaryngological investigations.

Modification of the Original ETGI

Endoscopic arytenoid abduction lateropexy (EAAL) has already been shown to be safe and effective for the treatment of vocal cord immobility of various etiologies.[9,10,13] However, the small glottic area of newborns made the use of the original the ETGI difficult, so it had to be modified.[14] First was the miniaturization of the instrument to make it easier to maneuver in the neonatal glottis. The small glottic size and the thin soft tissue layer over the larynx require a shorter and less curved endolaryngeal portion of the pipe-stem compared to the curve of the adult-sized device, depicted in Figure 1. Second was the conversion to the neonatal Miller laryngoscope (size 0; Welch Allyn, Skaneateles Falls, NY), which provides a good view for the lateralization of the left arytenoid cartilage (in three cases). In the last patient, a Macintosh Baby Laryngoscope (Welch Allyn) was used to expose the larynx.

Surgical Technique

Unilateral, left-sided EAAL was performed in four neonates on the 4th, 5th, 5th, and 27th day of life, respectively. All operations were performed under general anesthesia via total intravenous anesthesia and high-frequency supraglottic jet ventilation with continuous, strict monitoring of saturation and end-tidal CO_2 and readiness for possible intubation. Jet ventilation was performed by using the Acutronic Ams 1000 device

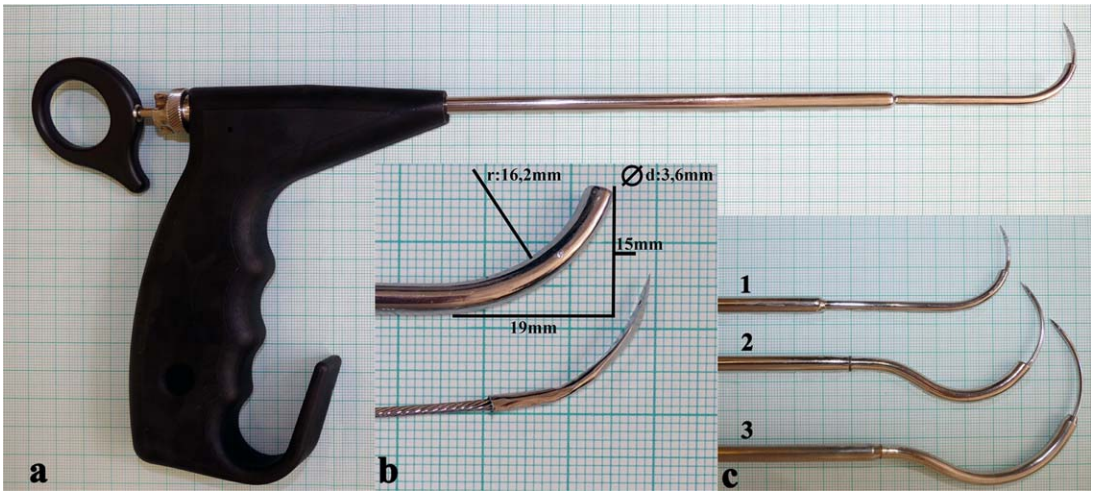

Fig. 1. Endolaryngeal thread guide instrument. (a) Handling, stem-pipe, and curved blade in pushed-out position (stem-pipe and blade designed for infants). (b) Stem-pipe and blade designed for infants. d = external diameter; r = radius of curvature. (c) 1) Stem-pipe and blade designed for infants, 2) stem-pipe and blade designed for women, and 3) stem-pipe and blade designed for men. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

TABLE II.
Details of the Surgery and Events of the Postoperative Care.

Patient/ Sex	EAAL, Days After Birth	Endolaryngeal Surgical Time, min	Postoperative Complication	Extubation, Postoperative Day	Reintubation, Postoperative Day	Oral Feeding, Postoperative Day
#1/M	4th	6	N	5th	N	7th
#2/F	5th	5	Laryngeal edema	7th	26th–32th	10th
#3/F	5th	8	N	3th	N	4th
#4/M	27th	6	N	7th	N	9th

EAAL = endoscopic arytenoid abduction lateropexy; F = female; M = male; N = none.

(Acutronic Medical Systems, Hirzel, Switzerland) with the following parameters: inhalation time = 40% to 50%, frequency = 50 to 60/min, volume = 200 to 300 mL, respiratory minute volume = 1.2 to 1.5 L; pressure = 50 mbar. The procedure began with direct endoscopic examination of the upper and lower airways to the level of the distal trachea with a rigid 0° and 30° endoscope. Performance of the EAAL followed immediately afterward during the same session.

Apart from the size and structural changes of the ETGI, the lateralization of the arytenoid cartilage was performed as described in our earlier publication.[9] After disinfection of the laryngeal mucosa, the ETGI is led through the laryngoscope to the glottic level. The mobile arytenoid cartilage is tilted backward and upward with the end of the instrument. The built-in, curved blade is then pushed through, under the vocal process, and out to the surface of the neck. A nonabsorbable suture thread (0-Prolene; Ethicon, Somerville, NJ) is laced through the hole at the tip of the blade by an assistant surgeon. The doubled-over thread is pulled back with the blade, into the laryngeal cavity. After a repeated tilting of the arytenoid cartilage, the blade is pushed out with the thread above the vocal process to the outer surface of the neck. The assistant surgeon then cuts the double-folded thread to remove it from the blade tip. The blade is then pulled back into the laryngeal cavity, and the ETGI can be removed. A small skin incision is then created to withdraw the ends of the thread by a Jansen hook to the surface of the sternohyoid muscle. The corresponding ends are knotted above it.[9]

The total and the endolaryngeal operation time (from the introduction of the ETGI until its final removal) was noted. At the end of the surgery, the babies remained intubated for 3 to 7 days with an uncuffed tracheal tube (patients 1, 2, 4: inner diameter [ID] = 3.5 mm; patient 3: ID = 3 mm; Portex siliconized polyvinyl chloride oral/nasal uncuffed tracheal tube; Smiths Medical, Plymouth, MN). The size of the endotracheal tube was chosen by age- and weight-based formula according to the advice of the anesthesiologist.[15]

Parenteral antibiotic (amoxicillin/clavulanic acid, 25 mg/5 mg/kg for 12 hours) was administered for 4 days, and methylprednisolone (4 mg/kg) was administered for 7 days. On the day of extubation, the patients were given a steroid bolus. Nasogastric feeding was used for all patients while they were intubated. The postoperative management took place in the PICU in each case.

Follow-up

The functional outcomes of the surgery in terms of breathing, voice, swallowing, and overall satisfaction were evaluated by the quality of life (QOL) questionnaire of the Lausanne team.[16] Follow-up evaluations included regular endoscopic examinations under general anesthesia using a rigid 0° and 30° endoscope. The grade of the vocal cord movement recovery was noted. Body weight gain, length growth, and swallowing difficulty were systematically registered by the parents.[17] The voice samples were recorded with a high-sensitivity (40Hz–16kHz) condenser head microphone (ATM75; Audio-Technica, Machida, Tokyo, Japan) at a sampling frequency of 96 kHz (24-bit US-122MkII external soundcard; TASCAM, Montebello, CA), and analyzed by Praat 5.3.2.9. software (www.praat.org). The following acoustic parameters were recorded in this study: mean pitch, jitter, shimmer, and harmonics-to-noise ratio. Follow-up intervals were 17, 11, 13, and 55 months for the four patients, respectively.

RESULTS

The mean total surgical time was 17 minutes, with an average of 6 minutes spent on the endolaryngeal lateralization. No major perioperative or postoperative complications occurred. The postoperative timeline of events is presented in Table II. Extubation was considered safe on the 5th, 7th, 3th, and 7th postoperative day in the four patients, respectively. In the case of infant #2, extubation was attempted on the 4th postoperative day, but due to significant edema of the laryngeal mucosa, the intubation had to be prolonged by 3 days. Dyspnea and CO_2 retention were noted on the 26th postoperative day. Direct endoscopic examination revealed severe edema of the glottic soft tissues. Thus, reintubation and repeated antibiotics were required for another 6 days. All patients were able to tolerate a normal per os diet with no restriction in 1 to 3 days postextubation. The weight-for-age and length-for-age percentiles are depicted in Figure 2. The acoustic parameters, QOL scores, and characterization of vocal cord movement recovery are shown in Table III. Compared to the preoperative values, the QOL scores improved significantly in all cases. Based on the parent's observations, the voice of the patients was normal in three cases and slightly impaired in one case. In the first three patients, the crying sounds were powerful. Gurgling and cooing were similar to their siblings, according to the parents. Speech development was appropriate in the fourth case, which was the only case followed long enough (55 months) to be evaluated adequately. Partial regeneration of vocal cord movements was observed in two of the four cases: bilateral in infant #2 and unilateral in #3, at 6 and 3 weeks of age, respectively (Fig. 3). Lateralization sutures were not removed in any of the cases.

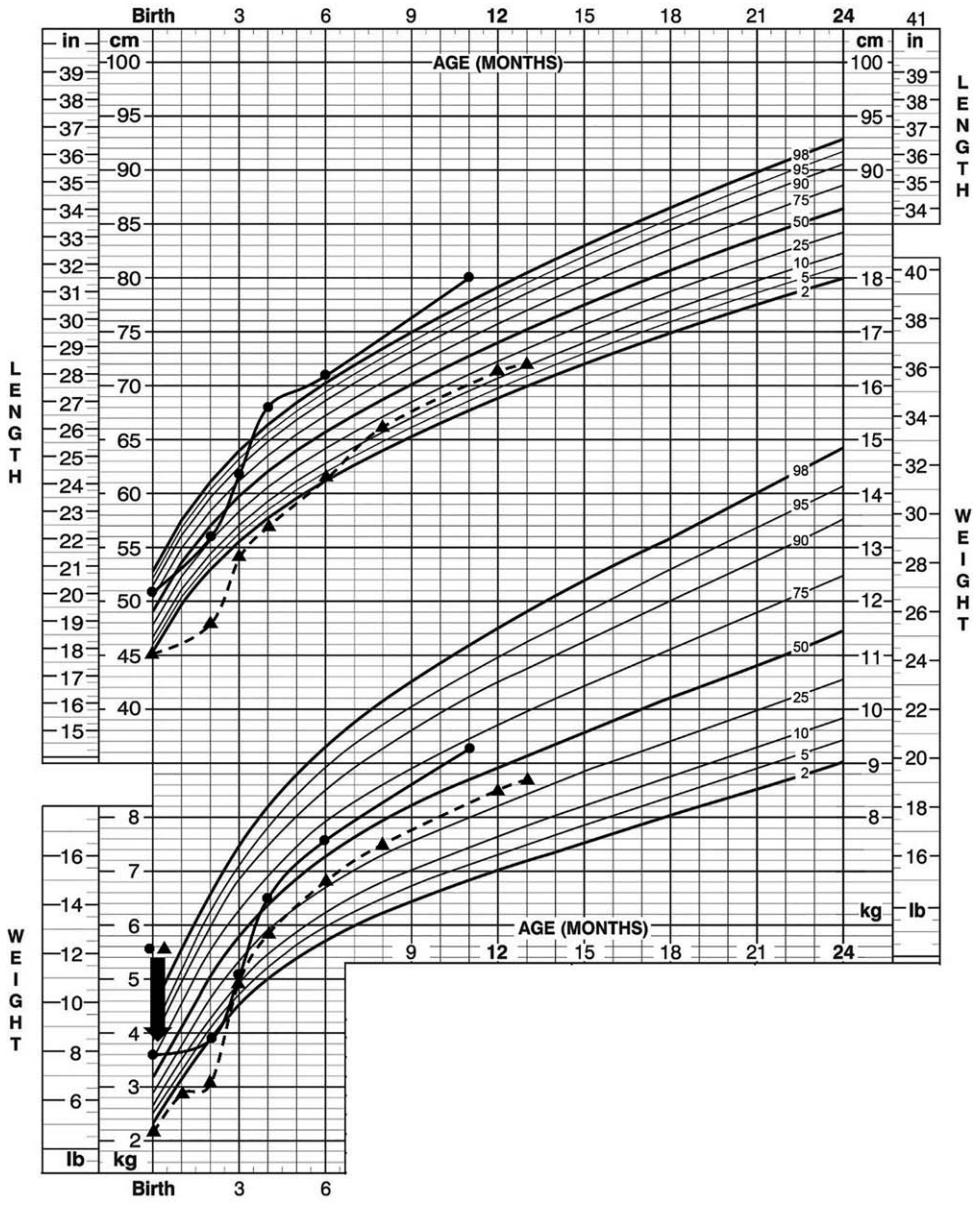

Fig. 2. Length-for-age and weight-for-age percentiles of the patients. (a) Length-for-age and weight-for-age percentiles of patients #2 and #3. Dots indicate patient #2; triangles indicate patient #3; arrow indicates day of surgery. (b) Length-for-age and weight-for-age percentiles of patients #1 and #4. Dots indicate patient #1; triangles indicate patient #4; arrows indicate day of surgery.

DISCUSSION

Due to the many etiologies of BVCP, the potential comorbidities, the related anatomical abnormalities, and the complex requirements of the treatment, many authors recommend a "watch and wait policy" in neonates.[5] However, the associated airway limitations significantly limit the normal physical activity and development of the child, even in milder cases.[2] In cases of severe dyspnea, tracheotomy is still the most frequently performed surgical intervention despite its many well-known risks, including severe complications such as airway stenosis and accidental decannulation, which can be life threatening.[4,7,8,18] The need to minimize surgery in the neonate and the many risks of neonatal anesthesia (small reserve capacity, high oxygen requirements, risk of hypothermia and hyperthermia, undiagnosed heart problems, limited cardiac output, etc.) make surgical options even more limited in this age group. The optimal surgical intervention would be both quick and reversible as well as provide an immediate adequate airway, acceptable voice quality, and good swallowing function. A simple suture lateralization technique of the vocal cord from an external approach was introduced by Zawadzka-Głos in children aged 1 year and older,[19] but this technique did not become popular. Triglia et al. applied arytenoid lateropexy from an external approach on 15 children between 1 month and 9 years old with more encouraging results; however, the undertaking of this relatively complex and long-lasting intervention is significant in neonates. Because of the

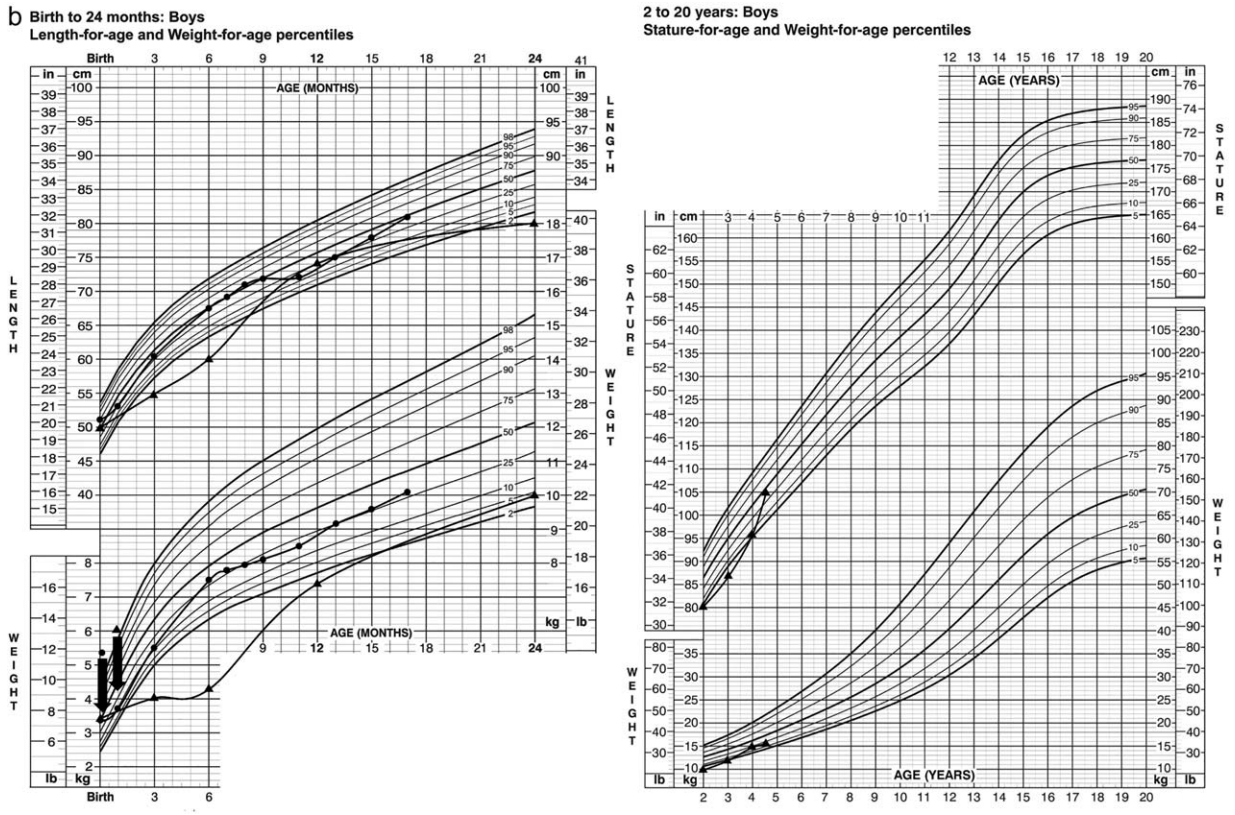

Fig. 2. (Continued)

extensive, surgical dissection of the arytenoid region and the resulting scar formation, this procedure is considered to be irreversible even on adults.[20–23]

Our preliminary results show that EAAL can be relatively easily and quickly performed with low surgical stress even in the first days of life. Moreover, it provides a stable, long-lasting, and wide airway that is potentially reversible because the endoscopically inserted lateralization sutures do not significantly disturb the anatomical structures. This has been proven in several adult cases in which definite reinnervation occurred.[9,10,12,15,24]

The supraglottic jet ventilation and the novel use of pediatric laryngoscopes ensure excellent visualization of the glottis with access unencumbered by an endotracheal tube. If jet ventilation is not available, however, this fast procedure can be performed under spontaneous ventilation with intermittent intubation.[9] Based on our experience, the new, modified ETGI is suitable for fast and safe maneuvering in the narrow laryngeal space of newborns. The blade is connected with the stem-pipe continuously; thus, the device can be removed promptly in case of the need for intubation (Fig. 1). Visual control during the technique is paramount. Moreover, the positioning of the lateralization suture can be made more precisely with endoscopic guidance. With these associated technologies and instrumentation, the procedure can be performed quickly and safely. This intrinsically reduces the potential complications from anesthesia and jet ventilation. In adult patients, no postoperative intubation, temporary tracheostomy, or intensive care are required after EAAL. Due to the limited anatomical space,

TABLE III.
Functional Outcomes of the Surgery.

Patient	Jitter, %	Shimmer, %	HNR, dB	Mean Pitch, Hz	QOL	Vocal Cord Movements	Follow-up, mo
#1/M	0.3	5.4	15.9	171.7	11	N	17
#2/F	5.9	20.1	3.5	261.1	8	R: complete abduction and adduction L: slight adduction	11
#3/F	0.4	4.6	16.4	360.4	7	R: complete abduction and adduction	13
#4/M	1.3	4.7	18.5	328.0	6	N	55

F = female; HNR = harmonic-to-noise ratio; L = left side, M = male; N = no movement; QOL = quality of life score; R = right side.

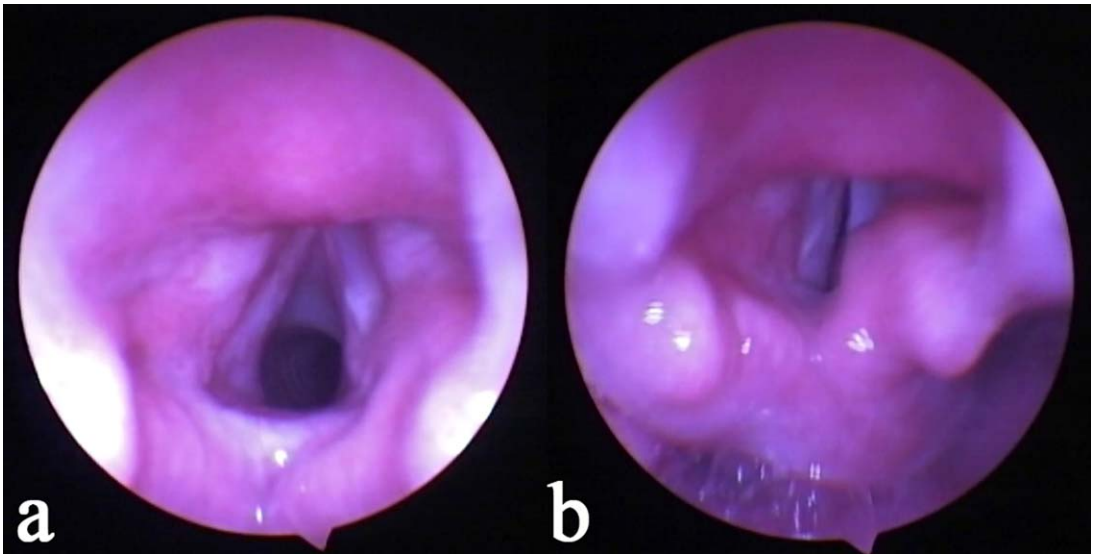

Fig. 3. Complete regeneration of the right vocal cord movements after left-sided endoscopic arytenoid abduction lateropexy (patient #3, 3rd postoperative week). (a) Right side abduction. (b) Right side adduction.

increased vulnerability, and swelling of the soft tissue of the neonates, a short-term postoperative intubation is always prudent along with parenteral steroid therapy. Temporary intubation may also help by the maintaining the lateralized position of the arytenoid cartilage, although our report did not compare this to any cases that were immediately extubated. Perioperative empiric intravenous antibiotic therapy is also indicated.

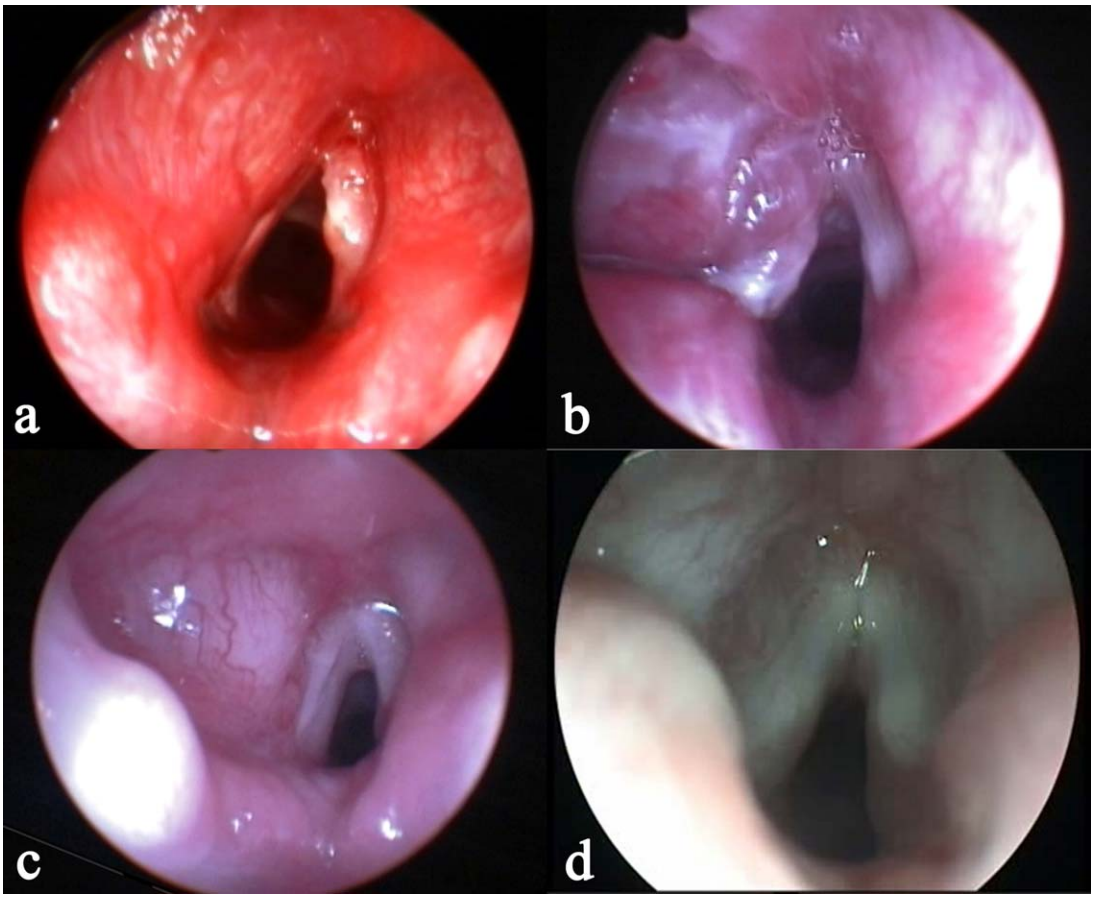

Fig. 4. Endoscopic pictures of the lateralized left vocal cord. (a) Patient #1 (3rd postoperative week). (b) Patient #2 (2nd postoperative week). (c) Patient #3 (2nd postoperative month). (d) Patient #4 (4th postoperative year).

The presented lateralization technique does not impair laryngeal sensation, which is essential for protective laryngeal reflexes.[25] This is consistent with our experience in adult patients who have not had significant aspiration after arytenoid cartilage lateralization. After the removal of the nasogastric feeding tube, the newborns in this series could be easily fed and nurtured. This is supported by parental reports and by the registered weight gain and length growth. Despite the comorbidities and the long hospitalizations, the weight-for-age and length-for-age percentiles show a normalization after the initial growth delay. The objective measurements of voice quality are very limited at this age, but the results of the voice analysis are consistent with the QOL questionnaire's results. The postoperative glottic configuration of a small angle in the anterior commissure and the straight and tensed vocal cords allows acceptable phonation closure in case of contralateral vocal cord recovery.[10,26] This not only allows voice improvement after spontaneous reinnervation, as was seen in the second and third case, but helps to maintain the airway patency. This procedure is reversible in adults, and therefore likely reversible in children. However, we did not undertake any reversal on the infants during this study period. Reversal needs to be carefully considered, because reinnervation of the two vocal cords does not necessarily occur simultaneously. We have observed in adults that when reversal is undertaken because the contralateral vocal cord's movement has recovered, the released (but potentially still paralyzed) vocal cord can remedialize after the suture removal.[27] Although that is acceptable in an adult, in the young and very small larynx this medialization might cause a significant increase in airway resistance. As the unilateral lateralization suture does not cause any swallowing or phonation impairment, it was not removed after partial functional recovery. This was in accord with the parents' decision. The suture removal can be considered in the future if endoscopic and/or laryngeal electromyographic examinations confirm the reinnervations or when the larynx has grown larger.

Endoscopic examinations proved the stable position of the lateralization sutures and the abducted arytenoid cartilage after 4 years in the one patient we followed for that long. This surgical intervention might be a long-term solution, even in fast-growing laryngeal structures (Fig. 4).

CONCLUSION

According to our preliminary results, the minimally invasive and quick EAAL might be a more favorable solution for neonatal BVCP than earlier treatment strategies. In one step, the airway can be maintained without the risk of any permanent damage to voice production. Good swallowing function is also preserved. In addition to these benefits, it should be easily reversible. The specially modified ETGI gives a fast and effective option to create the lateralized arytenoid position even in the technically challenging surgical context of a neonatal larynx. Follow-up long-term outcomes and additional patients need to be studied to further validate this procedure.

Acknowledgment

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II.

The Laryngoscope

Comparison of Endoscopic Techniques Designed for Posterior Glottic Stenosis—A Cadaver Morphometric Study

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Objectives/Hypothesis: Posterior glottic stenosis may cause more or less severe dyspnea. The popular endoscopic procedures have only a limited role in the treatment. Considering our clinical experiences, endoscopic arytenoid abduction lateropexy (EAAL) after proper mobilization of the fixed joints provides an effective option even in high-grade stenoses.

Study Design: To confirm these clinical observations, a morphometric study was performed in 100 cadaver larynges (50 male, 50 female) to objectively compare the endoscopic glottis-widening procedures.

Methods: The postoperative measurements of the posterior commissure following EAAL, classic vocal cord laterofixation (VCL), transverse cordotomy (TC), and arytenoidectomy (AE) were assessed by a digital image analyzer program. The distance between the vocal process of the lateralized vocal fold and the midline, the angle between the axis of the posterior commissure midpoint, and the vocal process and laryngeal median sagittal line were measured.

Results: EAAL was found to be more effective in improving the posterior glottis configuration; however, AE and VCL were beneficial as well.

Conclusions: Our morphometric study proved that organ-preserving EAAL provided more space in the posterior glottic area. Fibrous reconnection and contraction of the scar can be minimized in this way, which may be the clinical efficacy explanation.

Key Words: Arytenoid lateropexy, endoscopic laryngeal microsurgery, posterior glottic stenosis.

Level of Evidence: N/A.

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INTRODUCTION

The posterior commissure involves the dorsal third of the vocal cords, the cricoid lamina, the arytenoid cartilages, and the interarytenoid area with the interarytenoid muscles and their covering mucosa.[1,2] Injury may lead to scar and to posterior glottic stenosis (PGS), limiting normal glottic motion by resulting in one or both arytenoid cartilages becoming fixed in an adducted position. Bilateral fixation commonly causes severe dyspnea, which may require tracheostomy. In the past decades, prolonged intubation, because of the increase of patients undergoing assisted ventilation, has become the most frequent cause of PGS, occurring in approximately 1% of cases.[3] The effect is a pseudoparalysis of normally innervated vocal cords.[3–5]

The moderate to severe dyspnea caused by bilateral vocal cord fixation generally requires surgical intervention depending on the grade of the stenosis (e.g., Bogdasarian-Olson classification[6] [Table I]) and the experience of the surgical team. Several different procedures have been introduced,[7,8] but the treatment of this hazardous vocal fold fixation still poses a great challenge even today. A simple scar transection provides limited and short-lived success even in mild cases because of the destruction of the deeper layers of the posterior glottis and cricoarytenoid joints. Also, the connecting raw wound surfaces increase the risk for restenosis. This is a well-known problem of other widely used procedures such as the transverse cordotomy (TC)[9,10] or the arytenoidectomy (AE).[5] Moreover, due to the originally damaged state of the posterior commissure, the effect of these procedures may be to worsen the stenosis. Eckel et al., in a consecutive series of 32 bilateral vocal cord mechanical fixations (limitation of the cricoarytenoid joint's movements) only 44% decannulation rate could be achieved with these methods.[11] However, by open techniques these results could be improved to 100%,[11–13] but tracheostomy might have to be sustained for weeks, and many of these patients had to face a significant deterioration of laryngeal function and voice. By contrast, in our earlier studies[14,15] we presented a consecutive series of 42 patients with different grades of stenosis. All were treated successfully by a minimally invasive endoscopic method following the resection of fixating scar, and mobilization of the cricoarytenoid joints and a temporary endoscopic bilateral arytenoid lateropexy. This approach provided not only significant airway improvement but also a functional larynx secondary to vocal cord motion

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TABLE I.
Bogdasarian–Olson Classification for Posterior Glottic Stenosis.

Bogdasarian and Olson classified the extent of posterior glottic stenosis into the following four types:

Type I: Vocal process adhesion

Type II: Posterior commissure stenosis with scarring in the interarytenoid plane and internal surface of the posterior cricoid lamina

Type III: Posterior commissure stenosis with unilateral cricoarytenoid joint ankylosis

Type IV: Posterior commissure stenosis with bilateral cricoarytenoid joint ankylosis

recovery. The rate of success was found to be more favorable compared to other procedures. Many authors have previously suggested a stent, a keel,[12,13,16–18] or a mucosal flap[19] to keep open the posterior glottis space after the scar resection, but these interventions succeeded only in low-grade stenosis and also often required tracheostomy.

The purpose of our method is to provide the largest possible space in the posterior commissure, thus keeping the wounds apart until healing,[14,20] diminishing the chance of developing a fibrin cicatrix. Moreover, the durable separation of the opposing wound surfaces over a period of weeks counters the contraction forces of the scarring process due to the myofibroblasts in early healing.[21]

The widest aperture means maximal inspiratory abduction of the arytenoid cartilage relative to the cricoarytenoid joint anatomy. Our operation, referred to as arytenoid abduction lateropexy, which is based on physiological abduction, confers a better effect than the other endoscopic methods. The effectiveness of different glottis-enlarging techniques described in the literature cannot be analyzed easily. The case numbers are generally so low as to make it hard to study common groups. Only one procedure can be performed on one patient, so the different methods cannot be reasonably compared in clinical practice. The aim of this study, which was based on a large number of cadaver larynges, was to avoid this limitation. By assessing the effectiveness of different endoscopic procedures, each performed on the same cadaver larynx, an objective comparison was possible. This has not been done previously.

MATERIALS AND METHODS

Cadaver Workup and Documentation

One hundred freshly excised cadaver larynges (50 male and 50 female) were analyzed. For a better view of the glottic area the epiglottis and the vestibular folds were removed (Fig. 1). Larynges were inserted into a fixation device and secured with three screws along the cricoid cartilage, which resisted deformation caused by the screws. The screws were always in the same position in each larynx. High-resolution digital photos were taken from a top view with a Nikon D60 camera (Nikon Corp., Tokyo, Japan) fixed on a tripod, with a Nikon 18–55/F3.5-5.6 AF-S DX G VR lens. The fixation device made it possible to take all photos from a consistent position.

Fig. 1. Cadaver larynx in the fixating device. The supraglottic soft tissues and cartilages were removed to improve visualization.

In the first study, the effect of different simple suture-based glottis-widening techniques on the posterior glottic aperture were measured in 60 larynges (30 male and 30 female). First, the normal cadaveric position of the larynges was documented. Then four different suture lateralization maneuvers were performed, one by one, on the left side on each larynx. Typical needle holder and suture materials were used; the readily accessible glottis obviated the need for special instruments.

All procedures were performed according to the techniques described in the literature.

Suture Lateralization Procedures

Classic vocal cord laterofixation. The vocal cord was lateralized and fixed by a thread loop inserted on the vocal process or just anterior to it. There are two types: Lichtenberger's endo-extralaryngeal[22] and Ejnell's exo-endolaryngeal procedure.[23] In this study, the suture loop was placed according to Lichtenberger's concept,[22] which allows for a more precise loop formation around the vocal process (Fig. 2A).

Modified vocal cord laterofixation. Lichtenberger's later modification of vocal cord laterofixation (VCL)[12] was also examined, in which a second thread was inserted a couple of millimeters anteriorly from the original one (Fig. 2B).

Endoscopic arytenoid abduction lateropexy. In the endoscopic arytenoid abduction lateropexy procedure (EAAL),[14] the arytenoid cartilage was rocked into its maximally abducted position, and then a thread loop was placed round the vocal process (Fig. 2C).

These minimally destructive procedures were performed on each larynx. They were taken in turns so that the prior surgical technique would not affect the results. The thread loops were positioned into the position described in the original publications, and then knotted on the outer surface of the thyroid cartilage.

Schobel's external lateralization procedure (SELP). As the control group of the endoscopic methods, Schobel's external lateralization procedure[8] was performed last because it causes a greater amount of tissue damage. The arytenoid cartilage is tilted and fixed laterally with two submucosally placed sutures; one is knotted on the posterior margin and the second is placed around the superior horn of the thyroid cartilage (Fig. 2D).

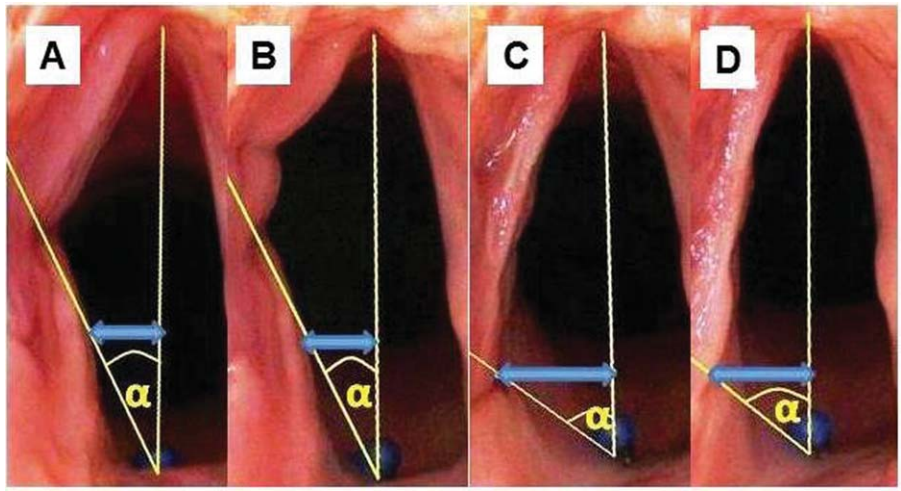

Fig. 2. Four different suture lateralizing techniques performed on the left side of the same cadaver larynx (larynx no. 18, male, 63 years old). The analyzed parameters describing the posterior glottis are marked: the midline–left vocal process distance (arrow), and the angle between vocal process–posterior commissure line and midline (α). (A) Vocal cord laterofixation (VCL), 1 suture. (B) VCL, 2 sutures. (C) Endoscopic arytenoid abduction lateropexy. (D) Schobel's method.

Resection Procedures

In the next part of the study, TC was compared to EAAL on 20 cadaver larynges, and finally AE was compared to EAAL on 20 different larynges. Because of the irreversibility of these procedures, two subgroups were created. Prior to the surgery, the supraglottic parts were also removed, and the same instrumentation was used for the fixation and documentation.

The Dennis and Kashima TC. In the Dennis and Kashima TC,[10] an incision was made at the vocal process, and a wedge-shaped defect was created by the removal of the middle third of the vocal cord (Fig. 3).

The Ossoff total AE. In order to simplify the procedure, the left arytenoid was completely removed along with the surface mucosa in the Ossoff total AE.[24] In common surgical practice, the medial mucosa is normally kept in place, but we wanted to evaluate the theoretical maximum efficacy of the surgical method so we removed it. In this study, cold instruments were used for the procedures (Fig. 4).

Digital Image Analysis

ImageJ digital picture analyzer software (National Institutes of Health, Bethesda, MD) was applied to measure the chosen parameters describing the posterior commissure; in the plane perpendicular to the median-sagittal plane of the larynges, the distance between the left vocal process and sagittal midline of the larynx was measured (Fig. 2, arrow). Then, the angles between the long axis of the vocal process, the posterior commissure midpoint, and the laryngeal median-sagittal line were measured (Fig. 2, α). In the 20 larynges treated with AE, the furthest point of the gained glottic area (for distance measurement) and the most posterior point of the left vocal cord (for the angle) were chosen (Fig. 4A). Repeated measure analysis of variance was used to compare the surgical results. Pairwise comparisons were performed based on estimated marginal means using the Sidak adjustment for multiple comparisons. SPSS 20.0 (IBM SPSS, Armonk, NY) was used for calculations.

RESULTS

All suture-based glottis-widening techniques provided a significantly larger posterior glottic area compared to the area in the cadaveric position (Fig. 5 and Fig. 6). In the case of VCL, no difference occurred in the results of the one- and two-sutures methods, and the second loop did not provide additional space in the

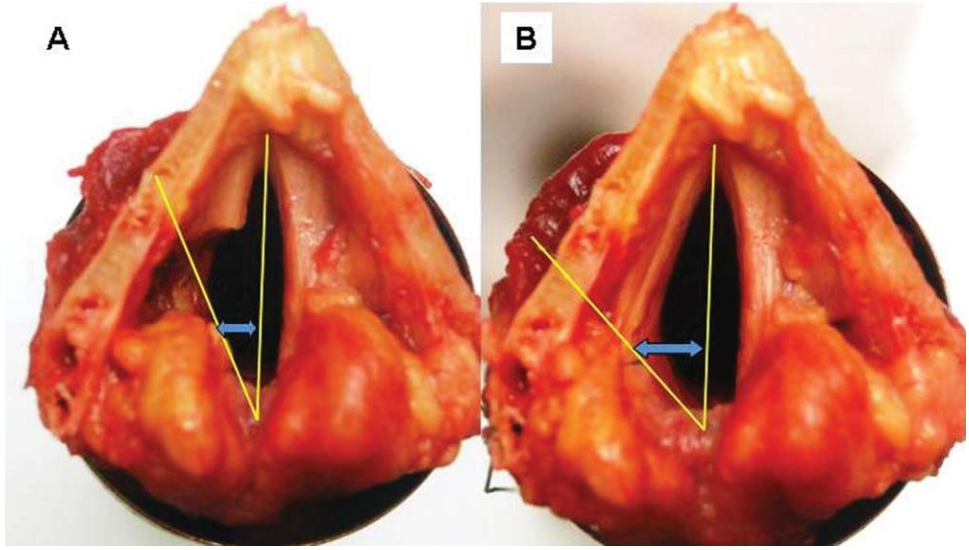

Fig. 3. Transverse cordotomy (A) and endoscopic arytenoid abduction lateropexy (B) (larynx no. 68, male, 74 years old). The analyzed parameters describing the posterior glottis are marked: the midline–left vocal process distance (blue arrows), and the angle between vocal process–posterior commissure line and midline (yellow).

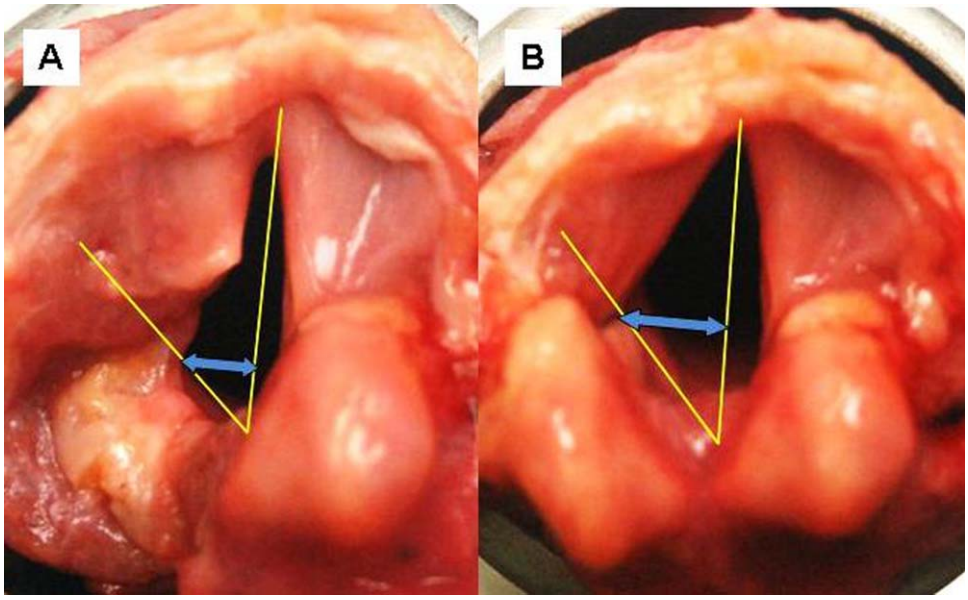

Fig. 4. Arytenoidectomy (A) and endoscopic arytenoid abduction lateropexy (B) (larynx no. 83, female, 68 years old). The analyzed parameters describing the posterior glottis are marked: the midline–left vocal process distance (blue arrows), and the angle between the vocal process–posterior commissure line and midline (yellow). [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

posterior glottis. EAAL and Schobel's method were proven to be significantly more effective than VCL. The measurements after EAAL were not significantly better than the change after SELP (Table II).

In the second part of the study, EAAL was compared to the resection surgical techniques. This proved to be the most effective suture lateralizing method (Table III). After TC, the configuration of the posterior glottic area essentially did not change. AE seemed to be less effective than EAAL because it caused no lateralization of the rest of the vocal cord.

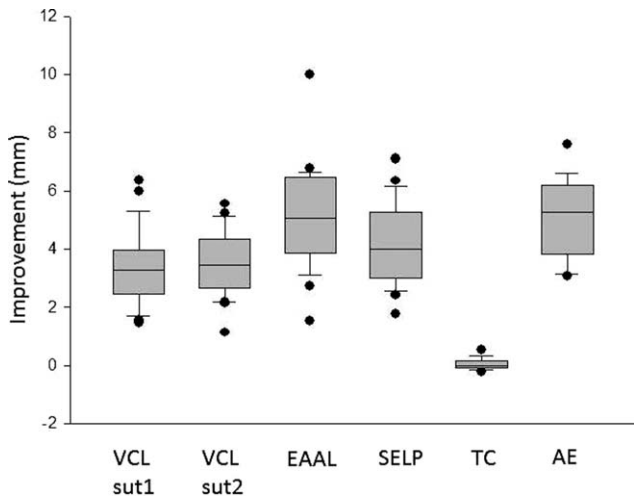

Fig. 5. The improvement of midline-vocal process distance after left-side manipulation. Box plot displaying the extremes, upper and lower quartiles, and the median of the difference between the cadaver and postoperative status. AE = arytenoidectomy; EAAL = endoscopic arytenoid abduction lateropexy; SELP = Schobel's method; sut = suture; TC = transverse chordotomy; VCL = vocal cord laterofixation.

DISCUSSION

Morphometric studies analyzing the results of different glottis-widening procedures had already been published. Eckel and Sittel used shock-frozen cadaver larynges to measure the efficacy of cordotomy and AE. Horizontal sections were produced, and cross-sectional areas of the vocal cords and arytenoids were measured using a computer-aided morphometry device.[25] Their method provided an objective comparison between the examined procedures, but it was expensive and time consuming, which likely limited the extension of the study as evidenced by the lack of follow-up work. The great anatomical variability of the larynx requires a large number of study specimens.[26] Other deficiencies were that the horizontal projection of the three-dimensional

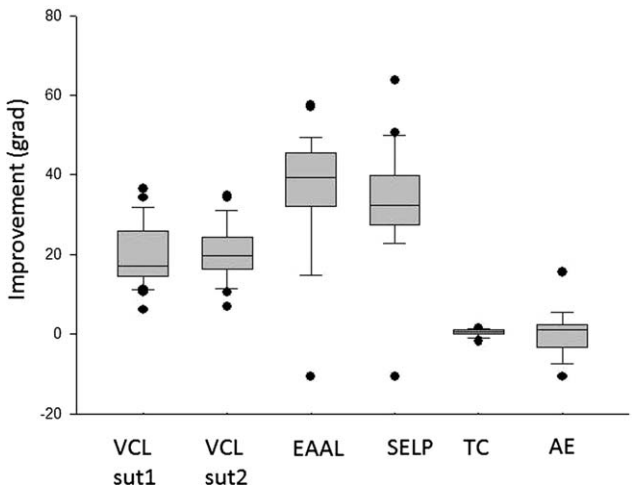

Fig. 6. The improvement of the angle of the posterior commissure (o = grad). AE = arytenoidectomy; EAAL = endoscopic arytenoid abduction lateropexy, grad = gradian; SELP = Schobel's method; TC = transverse cordotomy; VCL = vocal cord laterofixation.

TABLE II.
Statistical Correlations of the Results of Suture Lateralizing Procedures (n = 60): Comparison of the Horizontally Signed Method to the Vertically Written Method.

	VCL 1	VCL 2	SELP	EAAL
Midline-vocal process distance				
CP	*	*	*	*
VCL 1		NS	NS	†
VCL 2	NS		NS	†
SELP	NS	NS		NS
Angle in the posterior commissure				
CP	*	*	*	*
VCL 1		NS	†	†
VCL 2	NS		†	†
SELP	‡	‡		NS

*Significantly higher, $P < .0001$.
†Significantly higher, $P < .01$.
‡Significantly lower, $P < .01$.
CP = cadaver position; EAAL = endoscopic arytenoid abduction lateropexy; NS = not significant; SELP = Schobel's method; VCL = vocal cord laterofixation.

movements of the arytenoids might not have been analyzed by their method, and different glottis-widening methods could not be performed on the same organ.

These technical limitations were avoided by applying our simple digital image-based morphometric analysis method. When the fresh cadaver larynges are fixated in a standard position and in sharp high resolution, distortionless photos can be taken. The surgical anatomical parameters of different procedures can therefore be assessed in the plane perpendicular to the median-sagittal plane of the larynges. A large number of larynges were used, which allowed appropriate statistical comparison between procedures. Considering the anatomical variability of each larynx, repeated measures with each organ further strengthened our study.

Theoretically, an open posterior commissure after surgery for PGS should be tractioned in its new configuration to prevent restenosis. This can clearly be achieved when the arytenoid cartilages are repositioned to that of maximal. The movement of the cricoarytenoid joint is not a simple rotation around the vertical axis. This is generally considered to be the theoretical basis for simple VCL techniques and exists only in standard anatomy textbooks.[27] Wang has convincingly demonstrated that during abduction, the lateral sliding motion of the vocal process is accompanied by an upward and occasionally slightly posterior movement. Simultaneously, the arytenoid cartilage turns laterally and upward on the cricoid cartilage facet.[28,29]

TABLE III.
The Statistical Correlations Between the Results of EAAL and Resection Procedures (N = 20): Comparison of the Horizontally Signed Method to the Vertically Written One.

	AE	TC	EAAL
Midline-vocal process distance			
AE		*	NS
TC	†		†
EAAL	NS	*	
Angle in the posterior commissure			
AE		‡	§
TC	§		†
EAAL	‡	†	

*Significantly lower, $P < .0001$.
†Significantly higher, $P < .0001$.
‡Significantly lower, $P < .01$.
§Significantly higher, $P < .01$.
AE = arytenoidectomy; EAAL = endoscopic arytenoid abduction lateropexy, NS = not significant; TC = transverse cordotomy.

Our cadaver studies focused on the morphological configuration changes of the posterior glottic area caused by different glottis-widening procedures. They proved that this abducted position of the joint could be accomplished by tilting the arytenoid cartilage backward and then fixating it with a suture loop. EAAL is based on these maneuvers,[15] and therefore, in our opinion, provides better results than other suture lateralization methods. This technique spares the phonatory surface of the vocal cords, which should enable a better postoperative voice than procedures involving the resection of the glottis. When treating posterior glottic stenosis the procedure is performed bilaterally,[14] so the contrast with the results of different techniques is even more distinct. This study was performed on normal cadaver larynges, but these results can be extended to actual clinical circumstances when the posterior commissure is not pliable or stretchable. Our method, which cut the posterior glottic and cricoarytenoid intracapsular scars by CO_2 laser and a right-angle endoscopic blade,[14] allows the creation of this widened glottic configuration.

The analysis of VCL showed some improvement, but the second suture loop does not enlarge the posterior glottis. Schobel's method of external arytenoid lateropexy proved to be more effective, with the results being comparable to the results of minimally invasive EAAL. TC produced no significant area increase in the posterior commissure compared to the initial cadaveric position. TC may be effective in the treatment of dyspnea, but the configuration of the damaged posterior glottic area did not change. The arytenoid remained in a median position. As such, the expected postsurgical scar formation[10] may cause more severe dyspnea in the long run than in the case of bilateral vocal cord paralysis.

AE provided better results than VCL, but worse than EAAL. This intervention does not really change the position of the rest of the vocal cord. In some cases, vocal fold adduction happened because of the lack of connection between the arytenoid joint and the rest of the vocal cord. The scarred posterior commissure makes it difficult to create a mucosal flap, preserving the medial mucosa of the arytenoid, especially in the case of a fixed contralateral arytenoid. This clinical situation promotes significant restenosis. Another basic handicap of all the techniques involving vocal fold resection is that the removal of glottic tissue commonly causes irreversible loss of vocal function.

CONCLUSION

These morphometric cadaver studies confirmed that special maneuvers and suture fixation by EAAL can rock the arytenoid cartilage into its maximally abducted position, thereby providing the largest posterior glottic configuration compared to other endoscopic glottic-widening techniques. Fibrous reconnection and contraction of the scar tissue can be minimized in this way.

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III.

The Laryngoscope

How I Do It

A New Thread Guide Instrument for Endoscopic Arytenoid Lateropexy

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Objectives/Hypothesis: The varied etiology of bilateral vocal cord immobility (BVCI) requires a wide range of surgical approaches. A new endolaryngeal thread guide instrument (ETGI) is presented here for a minimally invasive endoscopic lateropexy of the arytenoid cartilage, which might serve as a basis for a simple solution for the main types of BVCI.

Study Design: Prospective study of BVCI patients who underwent surgery, including 22 bilateral vocal cord paralyses (BVCP), 12 mechanical fixations (MF), 10 posterior glottic stenoses, and two rheumatoid ankyloses.

Methods: The ETGI is based on a built-in movable curved blade with a hole at its tip to guide a thread in and out again between the skin and the laryngeal cavity. The loops formed around the arytenoid cartilage cause abduction. In cases of fixations, the cricoarytenoid joints were properly mobilized as a first step with a combination of cold technique and CO_2 laser.

Results: As spirometric tests proved, 32 patients achieved improved breathing ability. One temporary tracheostomy was necessary and one patient with ongoing radiotherapy could not be decannulated. Subjectively, twelve patients' voices improved or approximated normal quality due to complete vocal cord recoveries on at least one side after lateropexy was ceased. Incomplete recovery with more or less impaired voice was observed in 16 cases. Three MF patients and two BVCP patients with poor overall health condition had severe dysphonia.

Conclusions: Combined with simple and readily available methods, endoscopic arytenoid lateropexy is an effective solution for BVCIs with various etiologies. The ETGI facilitates this procedure with rapid and safe creation of fixating loops at the proper position.

Key Words: Arytenoid lateropexy, laryngeal microsurgery, laryngeal rheumatoid arthritis, vocal cord immobility.

Level of Evidence: 4.

***Laryngoscope,* 120:2002–2007, 2010**

INTRODUCTION

Bilateral vocal cord immobility (BVCI) is a term used to describe vocal cords that are restricted secondary to neuropathy, muscular disorders, or mechanical fixation (MF).[1] The moderate to severe dyspnea generally requires surgical intervention. However, the recently suggested endoscopic treatment modalities[2,3] might restore the airway patency in bilateral vocal cord paralysis (BVCP), but treatment of MF often requires external procedures (e.g., laminotomy).[4,5] Potential reversibility of BVCP means a further therapeutic challenge that necessitates a complex assessment[6] and gradual application of those techniques that resect the glottic structures.[3,7] Our earlier studies demonstrated long-term dependable results if the arytenoid cartilage is directly lateralized to the normal abducted position[8] by endoscopically inserted sutures. We observed the benefit of this procedure not exclusively in BVCP[9] but even in severe cases of MF after proper mobilization of the cricoarytenoid joint (CAJ).[10]

Nevertheless, the correct creation of this more posterior location of fixating loop is practically impossible through an externally inserted needle as it is described by the Ejnell's procedure.[11] This special suture placement is also a challenge for the original Lichtenberger device[10,12] because the thyroid cartilage is more dense in that area. Moreover, these techniques share a common problem, that is fixating threads are led through the oral cavity, which increases the risk of perichondritis, one of the possible complications of these procedures.[9,12,13] For this reason, as demonstrated by the result of a series of BVCI patients with different etiology, a new procedure performed with the prototype of an endolaryngeal instrument is introduced here. This thread guide device is

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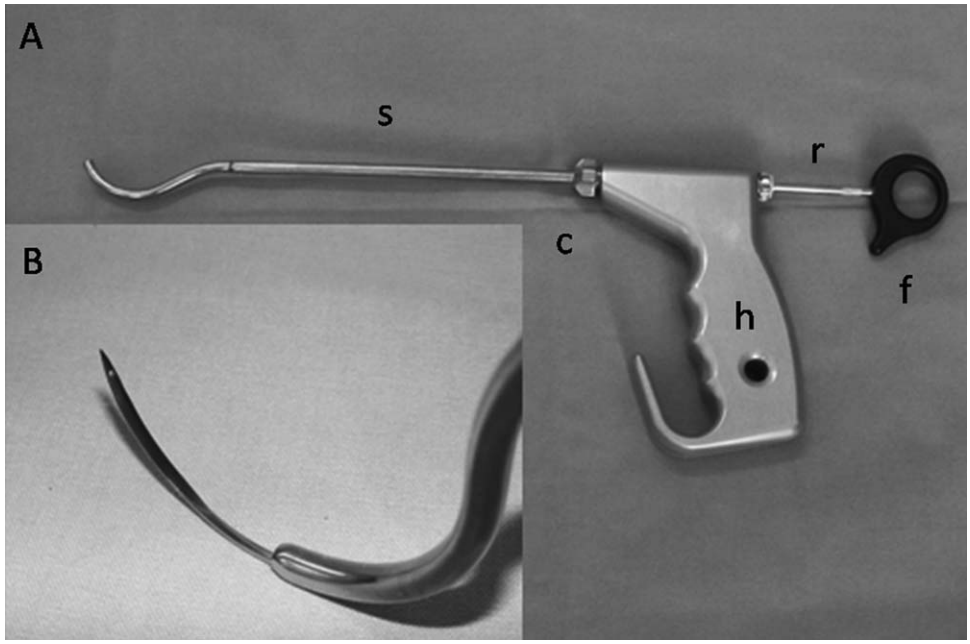

Fig. 1. The endolaryngeal thread guide instrument (ETGI). (A) The parts of the ETGI (the blade is pulled back). (B) The built-in, movable, curved blade in a pushed-out position with a hole at its tip. s = steel pipe stem; r = rod; h = handle; c = clamping screw; f = finger clip.

purposely designed for safe, accurate, and fast suture loop creation for the endoscopic arytenoid lateropexy (EAL).

MATERIALS AND METHODS

The principle of the endolaryngeal thread guide instrument (ETGI) is the utilization of a built-in, movable curved blade with a hole at its tip (Fig. 1B) allowing a suture thread to be guided in and out between the exterior surface of the neck and the internal laryngeal cavity. The stem of the instrument is a rigid steel pipe, curved at its distal, blade-holding end, created to fit into midsized, closed laryngoscopes. The second component is a rod, largely cased within the steel pipe stem. At the uncased proximal end of the rod is a freely rotating finger

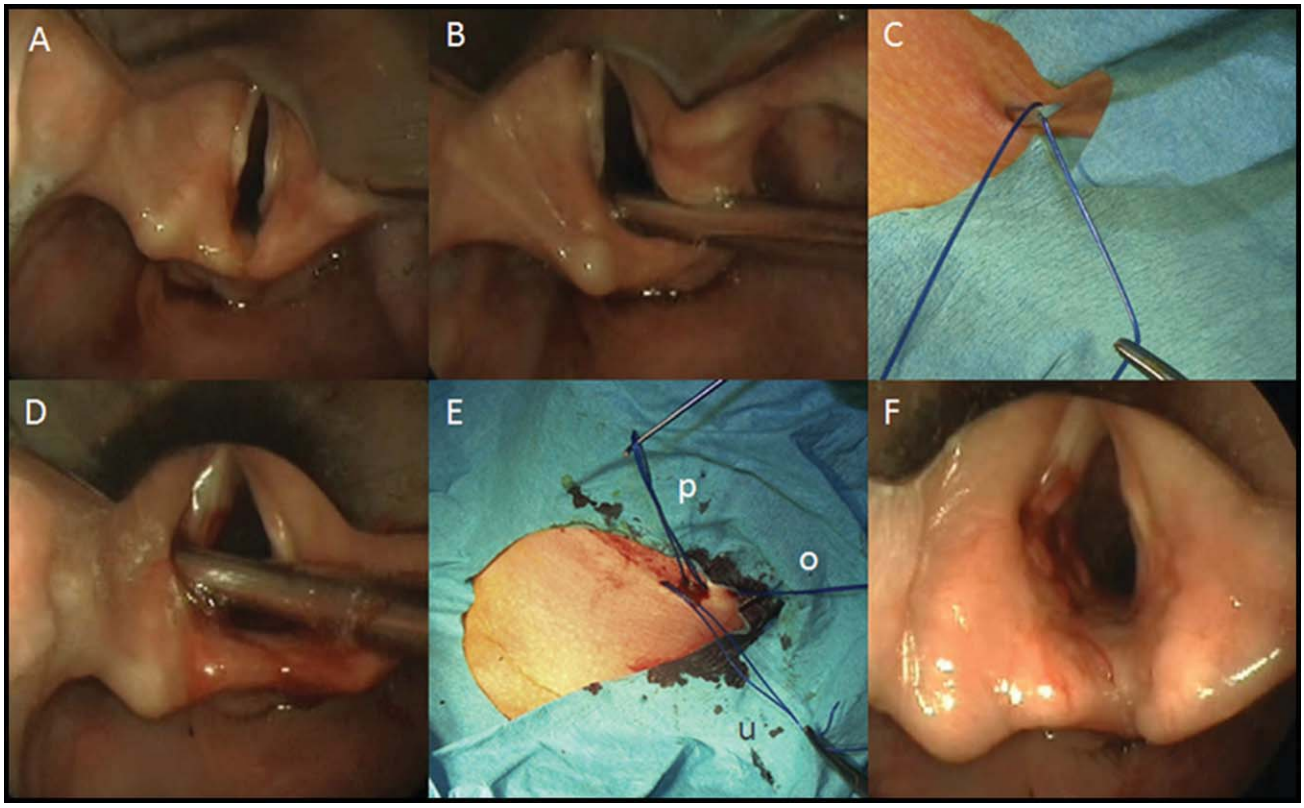

Fig. 2. Intraoperative pictures of a 67-year-old female demonstrate the efficacy of the method even in a small female larynx (see detailed explanation in the text); ends of threads situated under the vocal process (u); ends of threads situated over the vocal process (o) are just being pulled back (p) under the skin through a small skin incision by a Jansen hook.

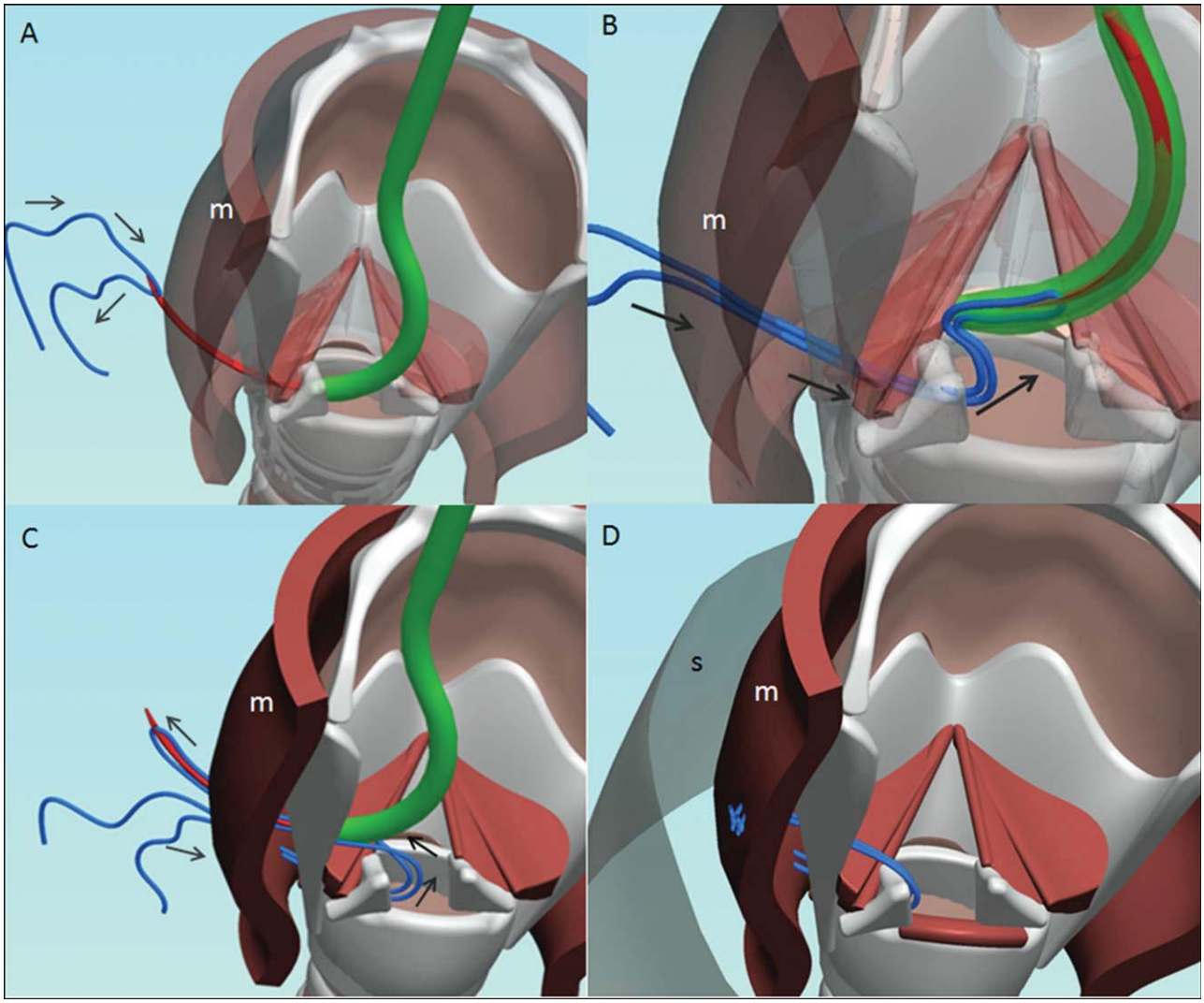

Fig. 3. Schematic drawing of the procedure (detailed in the text). The skin (s) is illustrated only on the last picture to achieve better visualization. Arrows indicate the direction of the thread guiding. m = sternohyoid muscle.

clip. At the distal end of the rod is the curved blade, appropriately designed to fit the curvature of its stem casing. The connection between the blade and the rod is fixed but flexible, ensuring forceful blade movement on exit and re-entry of the curved stem end. The pull and push of the finger clip (with the thumb) causes the in-and-out blade movement from the stem end. At rest, the blade is inside the curved stem end. The third component of the instrument is the ergonomic handle, which also serves as a shaft to hold the instrument in a straight position. The steel stem of the instrument is fixed to the handle with a clamping screw after turning it to the desired direction. The structural rigidity of the ETGI ensures easy penetration through the thyroid cartilage. The device has the approval of the Hungarian Health Care Institute.

General anesthesia combined with supraglottic jet ventilation is suggested. For the sake of maneuverability, the larynx is exposed with a Weerda laryngoscope (Fig. 2A) or with a Macintosh laryngoscope (in three females with difficult direct laryngoscopy). In cases of MF a strong, right-angled, saber-shaped scythe designed by our team is used for dividing the adhesions in CAJ, which is completed with CO_2 laser scar excision in posterior glottic stenosis (PGS).[10] In cases of BVCP unilateral EAL was performed, and in cases of MF bilateral EAL was performed. After disinfection of the mucosa the ETGI is led through the laryngoscope to the glottic level. The mobile (or mobilized) arytenoid cartilage is tilted backward and upward with the end of the instrument (Fig. 2B). The built-in, curved blade is then pushed through under the vocal process out to the surface of the neck (Fig. 3A). A nonabsorbable suture thread (Prolene 1.0; Ethicon, Somerville, NJ) is laced through the hole at the tip of the blade by an assistant surgeon (Fig. 2C and Fig. 3A). The doubled-over thread is pulled back with the blade, into the laryngeal cavity (Fig. 3B). After a repeated tilting of the arytenoid cartilage (Fig. 2D), the blade is pushed out with the thread above the vocal process to the outer surface of the neck (Fig. 3C). The assistant surgeon then cuts the double-folded thread to remove it from the blade tip. The blade is then pulled back into the laryngeal cavity, and the ETGI can be removed. A small skin incision (approximately 5 mm) is then created to withdraw the ends of the thread by a Jansen hook to the surface of the sternohyoid muscle (Fig. 2E). The corresponding ends are knotted above it (Fig. 3D). This simple procedure enables the endoscopic creation of two fixating loops in one step at suitable laryngeal locations, providing maximal physiological abduction of the arytenoid cartilage (Fig. 2F and Fig. 3D) within 5 minutes. In case of PGS a topical mitomycin-C

TABLE I.
Early and Late Postoperative Spirometric Results.

Bilateral recurrent nerve paralyses (n = 22; female/male = 17/5)				
	Age (years)	Preop*	PIF (l/s)Postop†	Final results
Mean	53.0	1.47	2.39	2.79
Min./max.	26/78	0.5/2.12	0.78/3.62	1.75/4.0
SD	±12.4	±0.42	±0.78	±0.67
Mechanical fixations Posterior glottic stenoses (n = 10; female/male = 3/7)				
	Age (years)	Preop‡	PIF (l/s) Postop	Final results
Mean	45	1.77	2.72	4.04
Min./max.	28/66	1.25/2.37	1.75/4.37	2.7/5.62
SD	±15.65	±0.45	±0.83	±0.98
Rheumatoid arthritis with ankylosis (n = 2; female/male = 1/1)				
	Sex/Age (years)	Preop	PIF (l/s) Postop	12th month
	female/49	1.15	×1.87	1.75
	male/18	1.85	2.25	2.37

The normative PIF value[16] in mixed-gender, healthy, young population is 4 L/s. In cases of unilateral VCP the PIF is about 70% to 80% of the normative value.[17] These facts suggest that the postoperative PIF of these older, dominantly female BVCP patients approximates to the theoretical maximum value, therefore the glottic configuration of EAL (Fig. 3A) is similar to a unilateral VCP patient in inspiration.

*One patient with cannula, two intubated patients, and three patients with severe suffocation were not measured.

†Three patients with cannula and two patients with severe suffocation were not measured.

‡Temporary tracheostomy for 2 weeks.

×One patient was not decannulated.

◆At least 1 year after EAL (patients with advanced esophageal tumor died in the 6th and 8th month).

PIF = peak inspiratory flow; SD = standard deviation.

application is considered.[10,14,15] In the peri- and postoperative period parenteral antibiotics, steroids for a few days, and speech prohibition for a week are suggested.[10] The suggested hospitalization is about 3 days. The sutures can be removed if recovery is detected at BVCP or in MF after 8 weeks once re-epithelialization in the posterior commissure was confirmed.

Patients

From 2005 to 2008, 34 consecutive patients (21 females, 13 males) were diagnosed and treated by ETGI for BVCI. Their follow-up was between 12 months and 47 months (mean, 27 months). The ages ranged from 18 to 68 years with a mean of 49 years. There were 22 patients in the BVCP group (surgical complications of 18 thyroid surgery and one cricotracheal resection were three esophageal tumor infiltrations of the recurrent laryngeal nerves). Ten of 12 cases of MF were considered being PGS. Two patients had laryngeal involvement of rheumatoid arthritis (RA). After receiving information about the possibility of worsening voice quality, all of the patients chose EAL instead of tracheostomy or the "watch and wait" policy. The study was approved by the Institutional Review Board of Szeged University.

RESULTS

In all patients, the ETGI successfully enabled the creation of fixating loops at the effective laryngeal positions. In one immune-suppressed female with RA and one male

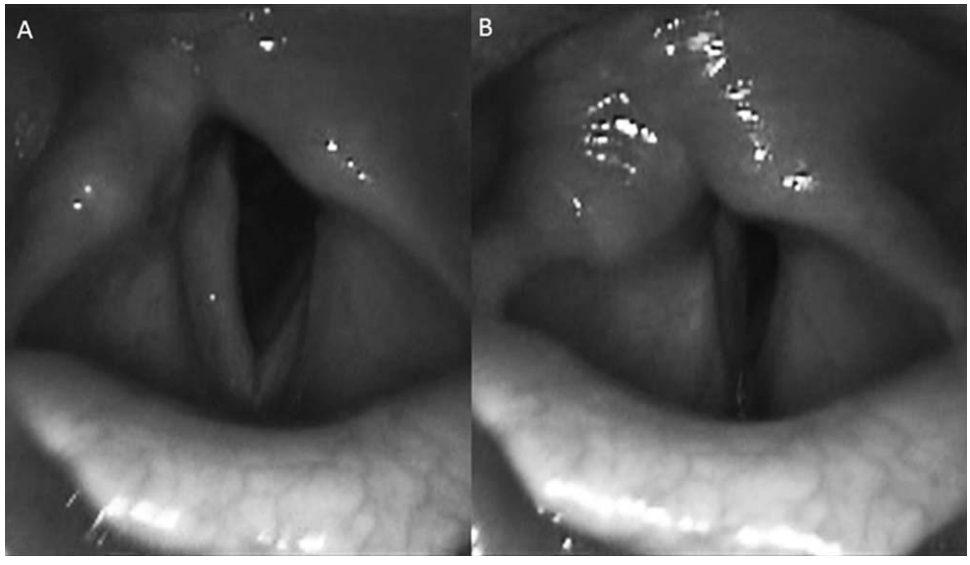

Fig. 4. Late result of endoscopic arytenoid lateropexy (67-year-old female demonstrated in Fig. 2). (A) At the end of the 12th month there is no medialization in the position of the lateralized left arytenoid cartilage. (B) Active adduction of the contralateral side can be observed during phonation, which allows acceptable voice production.

TABLE II.
Phoniatric Parameters Six Months After Endoscopic Arytenoid Lateropexy.

28 Patients* (MF = 10, BVCP = 18); Female/Male = 22/6; Mean Age = 52 y

	Acoustics			
	Pitch, Hz	HNR, dB	Jitt, %	Shim, %
Mean	203.72	20.64	0.93	4.91
Min/max	105.50/373.85	4.15/32.96	0.11/3.12	0.13/15.15
SD	±73.06	±7.37	±0.91	±4.32
	Aerodynamics		Perception	
	MPT, s	G	R	B
Mean	10.11	1.18	1.14	1.00
Min/max	2.11/33	0/3	0/3	0/3
SD	±6.95	±0.76	±0.69	±0.85

Normative values (www.fon.hum.uva.nl/praat/): Pitch = 200–240 Hz; harmonic to noise ratio (HNR) = >12 dB; Jitter (Jitt) = <1.04%; shimmer (Shim) = <3.81%; maximum phonation time (MPT) = >15 seconds; grade of hoarseness (G), roughness (R), breathiness (B): 0 = no deviance, 3 = severe deviance.

*Five patients were lost from the phoniatric follow-up.

MF = mechanical fixation; BVCP = bilateral vocal cord paralysis; SD = standard deviation.

with ongoing chemoradiotherapy due to an upper esophageal cancer, a temporary and a permanent tracheostomy had to be performed. Except for these two cases no significant postoperative complications, vocal cord remedialization have been observed. The remarkably improved[16,17] peak inspiratory flow (PIF) in the first postoperative day (62%) and the almost doubled values 1 year after the operation (Table I) indicated the immediate and long-term reliability of the procedure (Fig. 4A). In terms of phonation (Table II), from the 33 successfully treated patients a complete vocal cord recovery has been detected in six BVCPs (four bilateral, two unilateral) and in six MFs. Their voice parameters were at or near the normal quality after fixating suture removal. Further, 13 BVCP patients demonstrated incomplete, dominantly adduction recovery on the nonlaterofixed side (Fig. 4B). In three cases of MF the temporary bilateral EAL provided remarkable glottic enlargement but somewhat reduced adduction ability. These 16 patients had posterior phonation closure insufficiency, a more or less hoarse and breathy but socially acceptable voice. Further, two cases of high-grade PGS and the second RA case have had remarkably impaired adduction with severe dysphonia. The remaining two permanent BVCP patients with advanced esophageal tumor and chronic obstructive pulmonary disease associated with chronic laryngitis had severe aphonia.

DISCUSSION

During abduction, the lateral sliding motion of the vocal process is accompanied by an upward and occasionally slightly posterior movement, with the arytenoid cartilage turning laterally and upward on the cricoid cartilage facet.[8] This is the key to a really effective simple suture lateralization procedure, because it is obvious that the lower resistance against the fixating sutures arises if the joint is moved in its natural way. This position provided a more significant glottic enlargement (+55%, $P < .00002$) than the regular double-loop vocal cord laterofixation[12] in our objective morphometric study[18] made on 60 cadaver larynxes. This explains the PIF difference in a similar group of BVCP patients measured after the latter procedure (their postoperative mean, 2.01 l/s; increase, 45%).[19] Additionally, this position allows loops stay on the stable surface of cartilage and not let them slip to and cut through the vocal cord. This more posterior loop creating, however, is a challenge for the earlier methods.[12,20] Moreover, the ETGI ensures continuous suture guiding; there is no need for repeated external recharge of the instrument compared to Lichtenberger's device.[12] Ejnell's procedure is more time consuming because the thyroid cartilage is more widely exposed.[20] Considering these facts the accurate loop creation for EAL is safer and quicker by ETGI.

Further advantages of this compact technique are the following: 1) it can be applied easily in cases of difficulties of direct laryngoscopy (use of Macintosh laryngoscope); 2) the double loop creation with one maneuver, aside from the increased efficiency, diminishes the risk of vocal cord remedialization (e.g., a rupture of one of the sutures);[13,20] and 3) the thread moves within the disinfected laryngeal cavity and the skin, therefore the drug administration (to avoid the edema and perichondritis) can be diminished. The method utilizes the normal mechanism of abduction, thus the possible contraindications are limited. In these unselected cases of patients with isolated BVCI the two complications originated from the suppressed immune status. An airway infection might also be a contraindication.

CONCLUSION

EAL as a primary treatment might serve as a minimally invasive, effective, dynamic solution for most cases of BVCI. ETGI is specifically designed for this method, therefore it can facilitate this procedure. The simplicity of the intervention, the large degree of reversibility, the easily detectable laryngeal function recovery, and the good long-term results, might simplify the management of these patients with usually iatrogenic etiology.

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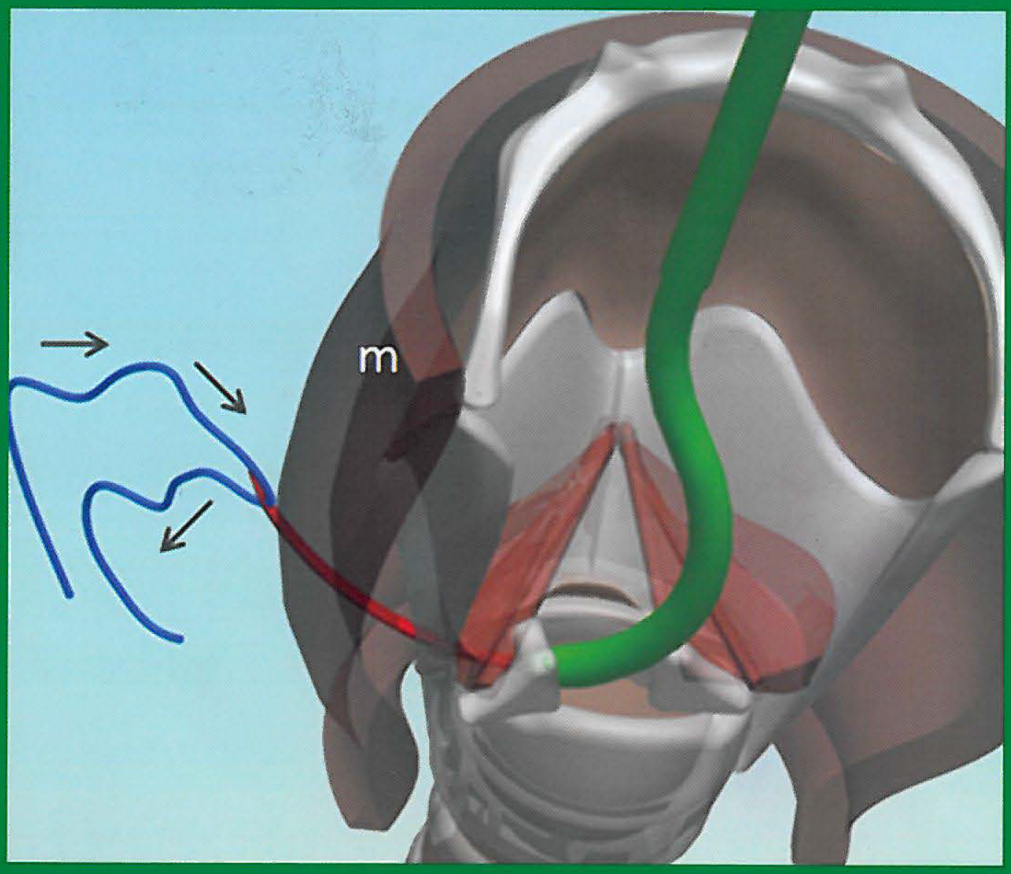

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IV.

how I do it

Endolaryngeal thread guide instrument (ETGI)

The endolaryngeal thread guide instrument (ETGI) is a relatively new development in the world of otorhinolaryngology and head and neck surgery [1]. In this article, we discuss using the ETGI for a minimally invasive endoscopic arytenoid lateropexy (EAL). The instrument can be used in the treatment of bilateral vocal cord immobility such as vocal cord paralysis, posterior commissure stenosis, ankylosis of crico-arytenoid joint and laryngeal web. It has also been successfully used in revision cases of failed glottis enlarging procedures.

Figure 1: Endolaryngeal thread guide instrument (ETGI).

The structure of the ETGI enables us to penetrate into the densest part of the thyroid cartilage. In this way, endoscopic arytenoid abduction lateropexy can be achieved by a double thread loop creation in one step. The laryngeal anatomical structures remain intact, which has many advantages in terms of therapeutical effect.

The airway enlargement is reversible to a large extent, so the laryngeal functions can be preserved in case of temporary inferior laryngeal nerve injury, or when this procedure is used for the prevention of restenosis, for example in the case of posterior glottic stenosis.

This is also a cost effective procedure, as the time the patient spends in theatre and post-operative care is reduced. Moreover, it simplifies the pre-operative assessment procedure and minimises the need for external procedures such as tracheostomy, laminotomy, etc.

Before the procedure the patient's status should be assessed for infection, immune deficiency, post chemo-radiotherapy or any other disease may cause inter or post-operative morbidity. These patients will need more complex administration of antibiotics.

Description of the instrument

The key component of the ETGI is based on a built-in, moveable, curved blade with a lacing hole (eye) at its tip in order to guide a thread in or out between the outer surface of the neck and the laryngeal cavity (Figure 1).

The stem of the instrument is a rigid steel pipe with a curve at its distal, blade-holding end, created to fit into midsized, closed laryngoscopes.

Considering the size differences of the larynx, three different measures of the steel pipe were designed with appropriate blades. The connection between the blade and the rod is fixed but flexible, ensuring forceful blade movement on exit and re-entry of the curved stem end. The blade is moved by a rod which is largely cased within the stem.

At the uncased proximal end of the rod is a freely rotating finger clip. The pull and push of the finger clip (with the thumb) causes the in-and-out blade movement from the stem end. At rest, the blade is completely cased. The last component of the instrument is the ergonomic handle, which also serves as a shaft to hold the instrument in a straight position. The stem of the instrument is fixed to the handle with a clamping screw after turning it to the desired direction. The appropriate structural rigidity of the ETGI ensures penetration through the special points of the thyroid cartilage [1].

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Declaration of Competing Interests
Shahram Madani is the Managing Director of MEGA Kft, who manufacture the endolaryngeal thread guide instrument (ETGI).

Surgical technique

For better manoeuverability, the biblade laryngoscope is suggested to expose the larynx. Afterwards, the mobility of the cricoarytenoid joints is examined by passive mobilisation. A rigid or ankylotic joint is mobilised by a strong right- angled endolaryngeal scythe designed by the authors. Then, the ETGI is led through the laryngoscope to the level of the glottis.

The arytenoid cartilage is tilted backwards and upwards with the tip of the instrument, and then the cased curved blade is pushed through under the vocal process of arytenoid cartilage out to the surface of the neck (Figure 2).

Following this, a non-absorbable thread (Prolene 1.0) is laced up to its midpoint through the eye of the blade. The thread folded this way is pulled back to the laryngeal cavity. After a repeated tilting of the arytenoid cartilage, the blade with the thread is pushed out above the vocal process. After cutting out the thread from the blade the instrument is withdrawn (Figure 3).

A 0.5cm skin incision is necessary for pulling back the thread ends to the level of the sternohyoid muscle to knot the autologous ends on its surface. This technique enables the creation of a double loop in one step, in the appropriate spot. The cut skin of the neck is re-edged with sterile strips or 4.0 Prolene suture (Figure 4).

Post operative care and follow-up

As a result of contact with the thyroid cartilage, high dose steroid and antibiotic administration is necessary for at least 4-7 days. In order to monitor for potentially reversible paralyses, patients are endoscopically followed up regularly, every 2-4 weeks. The sutures can be removed through a small skin re-incision if recovery is confirmed.

Advantages of the procedure

The accurate loop creation for EAL is safe and quick by ETGI. This provides a remarkable and long lasting breathing improvement right after the surgery (Figures 5-6).

Patients who wore a cannula before surgery can be de-cannulated during the first post-operative days. Further advantages of this compact technique compared to previous suture lateralisation techniques are:

- It can be applied easily in cases where there are difficulties with direct laryngoscopy (use of Macintosh laryngoscope)
- The double loop creation with one manoeuvre, aside from increased efficiency, diminishes the risk of vocal cord

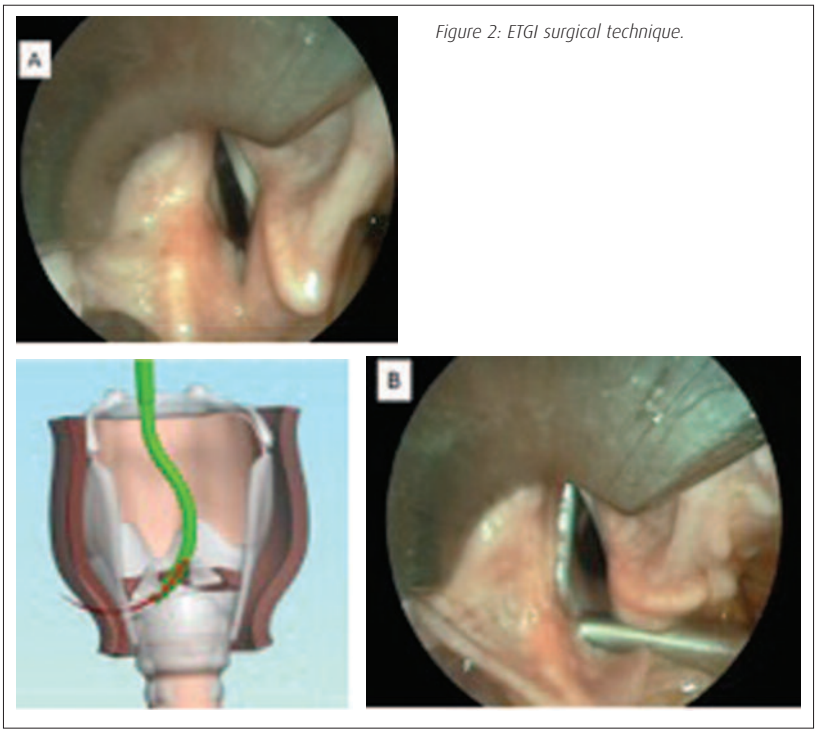

Figure 2: ETGI surgical technique.

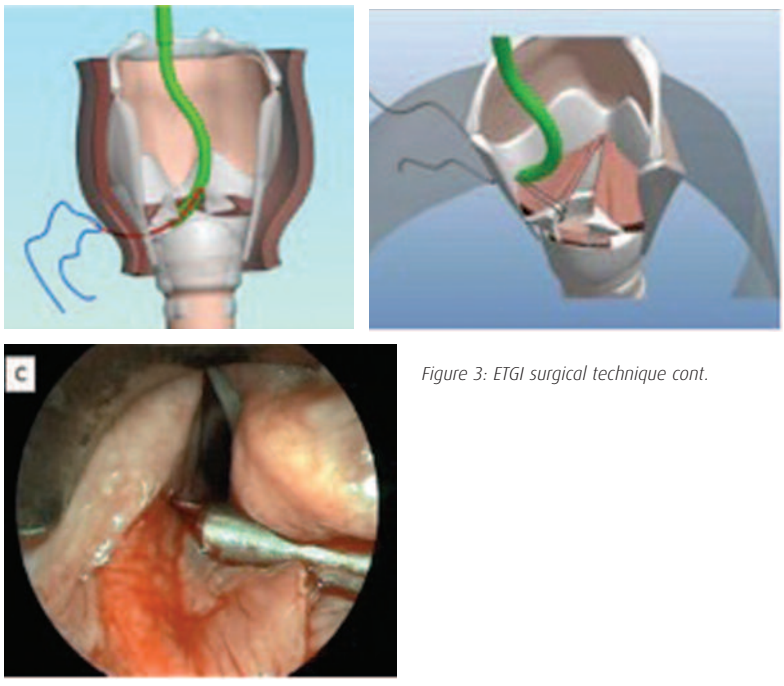

Figure 3: ETGI surgical technique cont.

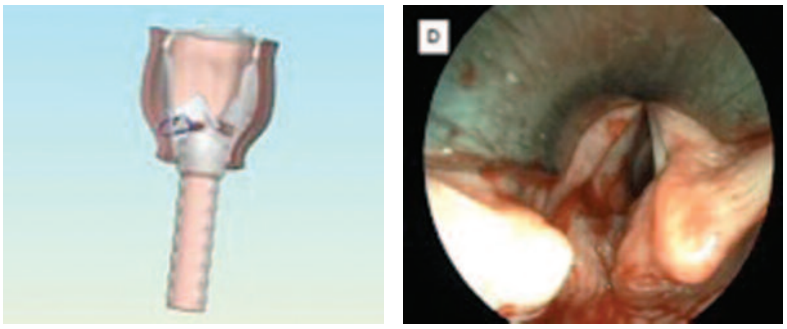

Figure 4: ETGI surgical technique cont.

Figure 5: (A) Pre-operative

Figure 5: (B) Post-operative

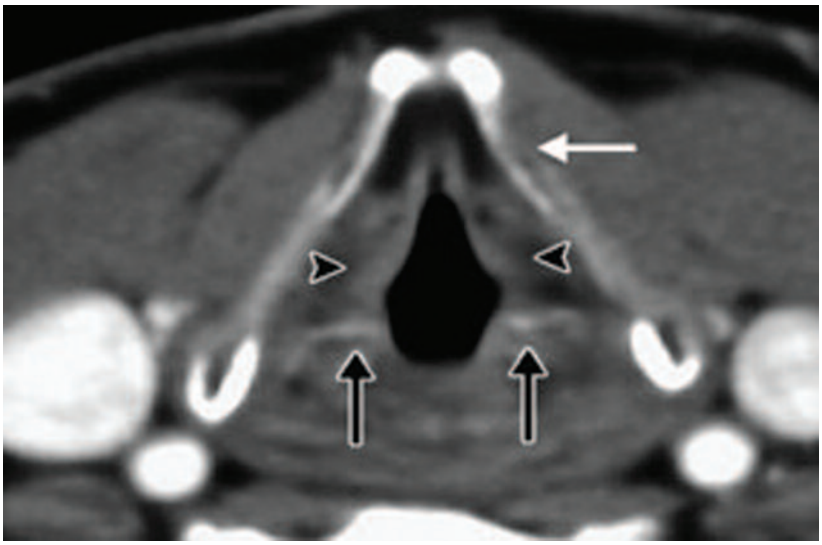

Figure 6: Post-operative neck computed tomography (CT) scan of the larynx after bilateral EAL. White arrow shows the output of the thread through the thyroid cartilage. Small black arrows show the laryngeal fold. Large black arrows indicate the lateralised arytenoid cartilage.

remedialisation (e.g. a rupture of one of the sutures)

- The thread moves within the disinfected laryngeal cavity and the skin, hence drug administration (to avoid oedema and perichondritis) can be diminished
- Preservation of the laryngeal fine structures ensures reversibility by simple removal of the loops
- Preservation of the mucosa of aryepiglottic fold and interarytenoid regions maintains the integrity of the protective laryngeal reflex [3], thus aspiration is negligible. As far as serious postoperative aspiration, which presented mostly in fluid intake, we found this markedly diminished after 2-7 days, as proven by radiological examinations (Barium swallow), and generally completely disappeared after a few weeks.

The method utilises the normal mechanism of abduction, so the possible contraindications are limited. However, our series has pointed out the potential complications as well. For example, suppressed immune status or ongoing airway infection may be relative contraindications.

Conclusion

Combined with simple and readily available methods, minimally invasive endoscopic arytenoid lateropexy may serve as the basis for an effective, dynamic solution even for the most difficult bilateral vocal fold immobility (VFI) with the preservation of fine laryngeal structures. The ETGI simplifies and facilitates this procedure with the rapid and safe creation of a double fixating loop at the proper position. Since there are different sizes of blades with different types of curvatures available, it can be used in a number of anatomical variations. With great extent of reversibility, easily detectable laryngeal function recovery, and good functional results, this surgical procedure may simplify the management of these patients in the long term. Thus, unnecessary diagnostic and therapeutic endeavours can be avoided in cases of usually iatrogenic etiology.

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Hangréstágító műtétek hatásosságának vizsgálata cadaver gégéken morphometriás módszerrel I. A hátsó commissura konfigurációjának változása

Sztanó Balázs, Szakács László, Smehák György, Madani Shahram, Jóri József, Rovó László

ÖSSZEFOGLALÁS: *Bevezetés:* Klinikánkon az elmúlt 10 évben új endoszkópos műtéti megoldást vezettünk be a hátsó commissura hegesedés kezelésére, mely a hegesedés megszüntetését követően végzett kétoldali kannaporc lateropexián alapul. A beavatkozás és a korábbi műtéttechnikai eljárások objektív összehasonlítása érdekében cadaver gégéken vizsgáltuk a különböző öltéstechnikákkal elérhető konfiguráció-változásokat a hátsó commissura területén.

Módszer: A méréseket 100 cadaver gégén (50 férfi, 50 női) végeztük. Az egy-egy gégén végzett különböző öltéstechnikák alkalmazása (klasszikus hangszalag laterofixatio (VCL) egy és két hurokkal, endoszkópos arytenoid lateropexia (EAL), Schobel-műtét) után a műtét sikere szempontjából fontos paramétereket digitális képelemző méréstechnikával értékeltük. Második lépésben értékeltük az arytenoidectomia és a transzverzális chordotomia (TC) várható eredményeit az előző módszerekkel összevetve.

Eredmény: A cadaver álláshoz képest valamennyi fonalhurokra épülő módszer szignifikánsan előnyösebb helyzetet biztosít a hátsó commissura területén, azonban a legjobb eredményt az EAL és a Schobel-technika után kaptuk. A VCL-nél nincs lényeges különbség az egy, illetve két öltés használata során. A Schobel-technika és az EAL minden esetben kedvezőbb paramétereket biztosított. TC során érdemi konfigurációváltozást nem találtunk, a kannaporc teljes eltávolítása azonban a hátsó commissura azonnali jelentős tágításához vezet.

Megbeszélés: Cadaver gégéken végzett vizsgálataink alátámasztják, hogy a kannaporc belégzési helyzethez közeli rögzítése biztosítja legtágabb, műtéttechnikai szempontból a legelőnyösebb helyzetet a hátsó commissura területén. Az arytenoidectomia szintén a hátsó commissura jelentős kitágítását eredményezi, azonban ebben az esetben számolni kell élőben az eljárásból adódó funkcionális veszteséggel.

KULCSSZAVAK: arytenoid lateropexia, endoszkópos gége mikrosebészet, hátsó commissura hegesedés

SUMMARY: *Introduction:* Posterior glottic stenosis (PGS) may cause more or less severe dyspnoe. One of the treatment options is lateralization of the fixed vocal folds after proper mobilization. Considering our clinical experiences the arytenoid lateropexy provide the best results (The vocal folds are fixed by sutures into their most abducted position). To confirm these clinical observations this morphometric study was performed in 100 cadaver larynges (50 male, 50 female) to find the ideal position for the lateralizing suture loop.

Method: Four different suture glottis widening operations were analyzed and the most important parameters of the posterior commissure were assessed by digital image analyzer program. The distance between the vocal process of the lateralized vocal fold and the midline and the angle in the posterior commissure between vocal process - posterior commissure line and midline were measured.

Results: All analyzed procedures provided a significant improvement in the posterior commissure. The endoscopic arytenoid lateropexy (EAL) seemed to be more effective, than classic vocal cord laterofixation (VCL), its results were comparable to the external Schobel's method.

Conclusion: Our morphometric study proved that arytenoid lateropexy provided more space in the posterior glottic area than simple laterofixation of the vocal fold.

BEVEZETÉS

A hátsó commissura anatómiailag magába foglalja a hangszalagok hátsó harmadát, a lamina cricoideát, a kannaporcokat és a köztük lévő izmokat a felettük elhelyezkedő nyálkahártyával (23, 24). Az itt kialakuló hátsó hegesedés a kannaporc addukciós helyzetben rögzüléséhez vezethet, ami kétoldali folyamat

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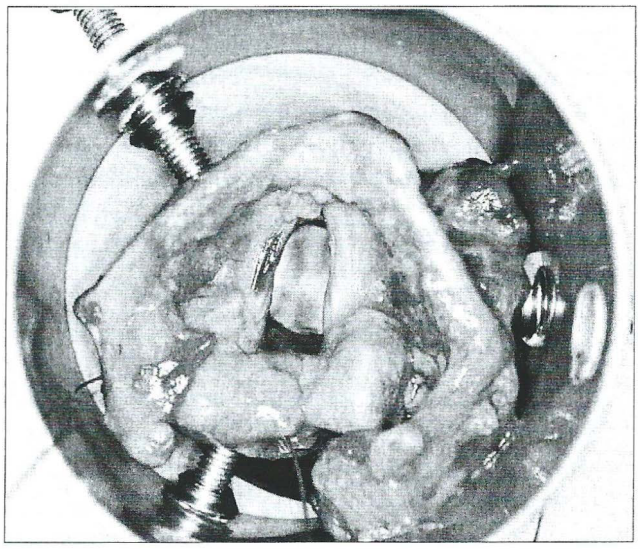
esetén súlyos fulladást okozhat. Az utóbbi évtizedekben az intenzív terápia során lélegeztetésre kerülő betegek körének és számának bővülése miatt a heges hátsó commissura szűkület (HCS) leggyakoribb oka a hosszan tartó intubáció, mely a betegek kb. 1%-ánál alakul ki (29). A folyamat végeredményeként az általában jól innervált hangszalagok pseudoparalysise jön létre (1, 3, 28).

A kétoldali paramedián hangszalaghelyzet miatti fulladás megoldására számos műtéti eljárást dolgoztak ki (14, 21, 22, 32), de a heges rögzítettség megszüntetése napjainkban is nagy kihívás. Elméletileg a műtéti technikák alapja a hangszalagok mozgását akadályozó hegek eltávolítása, mivel a gége motoros beidegzése ezekben az esetekben legtöbbször megtartott. Az egyszerű átvágás azonban a látszólag egyszerű esetekben is gyakran elégtelen, mivel a folyamathoz a hátsó commissura mélyebb rétegeinek és a cricoarytenoidealis ízület képleteinek destrukciója is társul. Ez magyarázza azt is, hogy a napjainkban kétoldali mozgáskorlátozottság megoldásaként gyakran alkalmazott arytenoidectomia, transzverzális chordotomia (3, 5) a heges, gyulladt területen csak limitált eredményt biztosít. Szintén kedvelt a külső behatolásból végzett laminotomia porc interpozitum alkalmazásával, azonban az esetek jelentős részében az interpozitum és a hegesedés síkja nem esik egybe, ami az eredményt kedvezőtlenül befolyásolja. Közismert módszer a heg átvágása után az interary térben lévő sebfelszínek érintkezésének megakadályozására külső vagy belső feltárásból stentek beültetése (12, 13, 15, 30, 31), vagy a sebfelszínt lokális nyálkahártya lebennyel való fedése (4). Ezeknél a műtéteknél azonban a siker döntően függ a cricoarytenoidealis ízület mobilitásától. Nem elhanyagolható szempont, hogy a stent miatt hosszú ideig tracheostomát kell fenntartani. Klinikánkon a probléma megoldására egy olyan minimálisan invazív endoszkópos megoldást dolgoztunk ki, mely során a cricoarytenoidealis ízület heges rögzítettségének megszűntetését követően stentelés helyett a kannaporcokat belégzési helyzetben varratokkal rögzítjük (9, 16, 17, 19, 25). A beavatkozás sikerének egyik alapvető szempontja, hogy a hátsó commissurában a kétoldali sebfelszín lehető legnagyobb távolságát biztosítsuk. Nyilvánvaló, hogy a gége anatómiai sajátosságait figyelembe véve ezt a kannaporc maximális belégzési helyzetében érhetjük el.

Az irodalomban leírt különböző öltéstechnikák effektivitása a klinikai gyakorlatban nehezen vizsgálható, mert az általában viszonylag kis betegszám miatt homogén vizsgálati csoportok nem alakíthatók ki, egy betegen pedig a különböző módszerek nem hasonlíthatók össze. Cadaver gégéken azonban a glottis struktúráját nem károsító öltéstechnikák egymást követően elvégezhetőek, így lehetőség nyílik a különböző endoszkópos eredmények objektív összevetésére.

Módszer

A vizsgálatok 100 frissen kipreparált cadaver gégén történtek (50 férfi és 50 női). A gégefedőt és az álhangszalagokat a hangrésre történő jobb rálátás céljából eltávolítottuk (*1. ábra*). A gégéket rögzítő eszközbe helyeztük, majd állványról nagy felbontású Nikon D60 digitális fényképezőgéppel (Nikon 18-55/F3.5-5.6 AF-S DX G VR objektív alkalmazásával) felülnézetből felvételeket készítettünk. A rögzítő eszköz kialakítása lehetővé teszi, hogy minden felvétel az adott gége megegyező helyzetében azonos távolságból történjék.

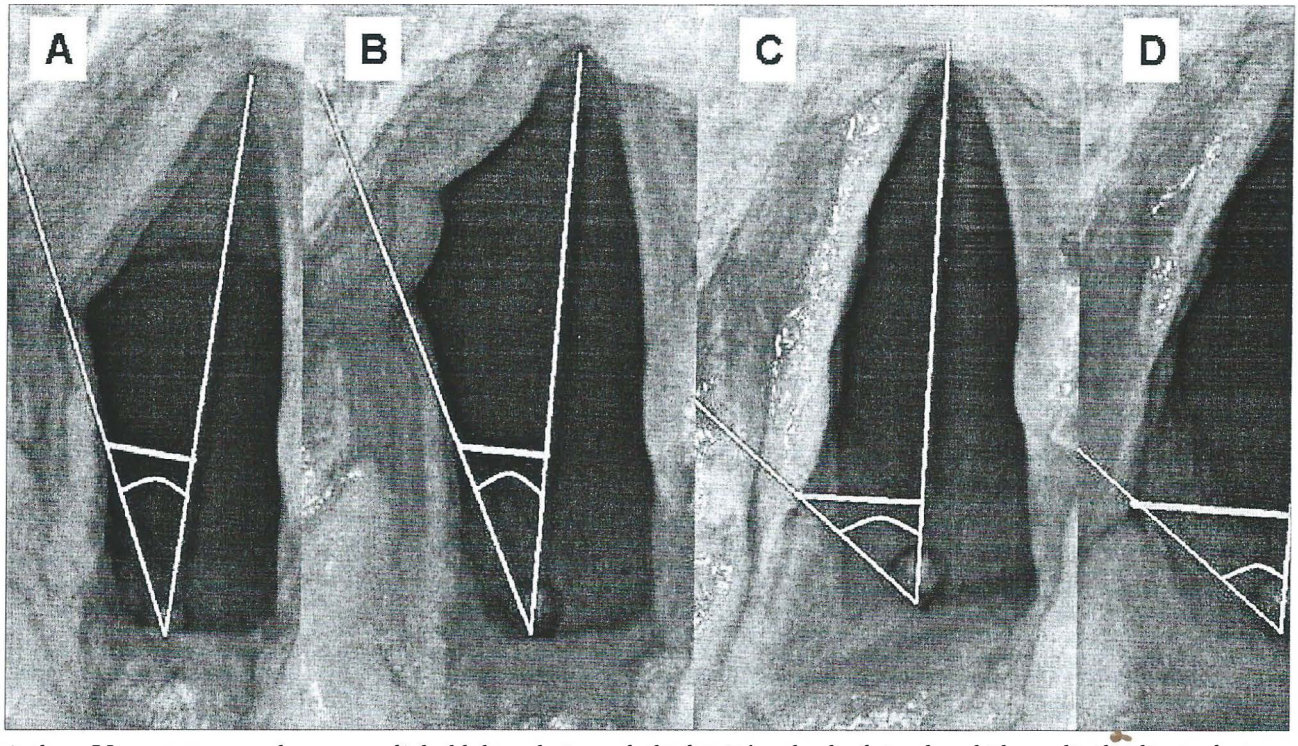


1. ábra. Cadaver gége a rögzítő eszközben. A jobb rálátás érdekében a supraglotticus részeket eltávolítottuk. A standard elhelyezés érdekében a rögzítési pontokat jelöltük

A vizsgálatok első részében 60 gégén (30 férfi és 30 női) vizsgáltuk a különböző öltéstechnikáknak a hátsó commissura konfigurációjára gyakorolt hatását. Első lépésben a gégét normál cadaver hangszalagállásban dokumentáltuk. Ezt követően a bal gégefélen négy különböző öltéstechnikára jellemző helyzetet alakítottunk ki normál tűfogó és varróanyag segítségével, majd a hurkokat a pajzsporcon csomóztuk. Speciális eszközökre a jól hozzáférhető glottis miatt nem volt szükség.

Az eljárásokat az irodalomban leírt módon végeztük.

1. A *klasszikus hangszalag laterofixációs technika* (VCL – vocal cord laterofixation), mely során a hangszalag oldalra rögzítését a processus vocalison vagy előtte elhelyezett varrathurokkal végzik. Ennek



2.ábra. Ugyanazon a cadaver gége bal oldalán elvégzett különböző fonaltechnikán alapuló lateralizáló eljárások összehasonlítása (18. gége, férfi, 63 éves). A vizsgált hátsó commissurát leíró paramétereket jelöltük: a középvonal és a bal processus vocalis távolságát, a hátsó commissurában a középvonal és a processus vocalis által bezárt szög
A: VCL 1 öltéssel, B: VCL 2 öltéssel, C: Schobel-műtét, D: EAL

két fő típusa ismert: a *Lichtenberger*-féle endo-exralaryngealis (11) és az *Ejnell*-féle exo-endolaryngealis öltési módszer (6). Egy másik mérési csoportot alkotva ezt a technikát – Lichtenberger után – egy, az előző varrathurok elé behelyezett második hurokkal egészítettük ki (11, 12) (*2A és 2B ábra*).

2. Az általunk javasolt *endoszkópos arytenoid lateropexia* (EAL) vizsgálatára a lateralizáló öltést a kannaporc előzetes maximális abdukciós helyzetbe történő „billentése" után helyeztük fel a processus vocalis köré (19) (*2D ábra*).
   A vizsgálat során e két, kis szöveti traumával járó technikát váltott sorrendben alkalmaztuk, hogy a műtéti destrukció statisztikailag ne befolyásolja a mérési eredményeket.
3. A nagyobb szöveti megterhelést jelentő *Schobel-műtétet* (S) alkalmaztuk utoljára. Két fonállal a kannaporcot submucosusan megkerülve az egyiket a pajzsporc hátsó élén átszúrva, a másikat a pajzsporc felső szarv körül hurkolva lateralizáltuk a gégefelet (14, 22) (*2C ábra*).

Vizsgálataink második részében 20–20 gégén arytenoid lateropexia elvégzését követően irreverzibilis *transzverzális chordotomiát* (TC), illetve *teljes arytenoidectomiát* (A) végeztünk (*3. és 4. ábra*).

A preparátumok értékeléséhez „Image J" digitális képelemző szoftvert alkalmaztunk. A hátsó commissura tágasságának leírására a következő egyszerűen mérhető paramétereket vizsgáltuk: a gége median sagittalis síkjára merőleges vetületében a sagittalis középvonal (az elülső és hátsó commissura közepét összekötő egyenes) és a processus vocalis távolságát, valamint a hátsó commissurában a processus vocalis középvonallal bezárt szögét mértük (*2. ábra*). Arytenoidectomia után a középvonal és a kialakított hangrés legtávolabbi pontja közötti távolságot vizsgáltuk, a szöget ebben az esetben a hangszalag él leghátsó pontjához képest határoztuk meg. A kapott eredményeket statisztikailag egymintás *T*-próbával értékeltük.

Eredmények

A cadaver álláshoz képest valamennyi fonalhurokra épülő módszer szignifikánsan tágabb viszonyokat eredményez (*1. és 2. táblázat*). VCL során nem találtunk érdemi különbséget az egy, illetve két öltés használata során, tehát a második öltés behelyezése nem biztosít tágabb viszonyokat a hátsó commissurában. A szintén endoszkópos beavatkozást modellező EAL esetében kedvezőbb paramétereket mértünk. A külső beavatkozásból történő *Schobel*-technika szintén egyértelműen szélesebb hátsó commissura feltárást alakított ki, mint a VCL, azonban ezek az eredmények némileg elmaradtak az EAL-től, bár a különbség ebben az esetben nem volt szignifikáns. TC

1. táblázat

A középvonal-processus vocalis távolság egyoldali beavatkozás után

	Átlag (mm)	SD +/-	Min. (mm)	Max. (mm)
Cadaver	1,69	0,67	0,58	3,26
VCL 1 öltés	5,15	1,23	2,78	6,56
VCL 2 öltés	5,32	0,99	2,75	6,63
S	6,04	1,39	3,19	9,35
EAL	7,22	1,45	3,15	11,11
TC	1,83	0,66	0,66	3,26
A	6,63	1,91	4,14	8,66

VCL: hangszalag laterofixatio, S: Schobel-műtét, EAL: endoszkópos arytenoid lateropexia, TC: transzverz chordotomia, A: arytenoidectomia

2. táblázat

A hátsó commissura szöge egyoldali beavatkozás után (° = fok)

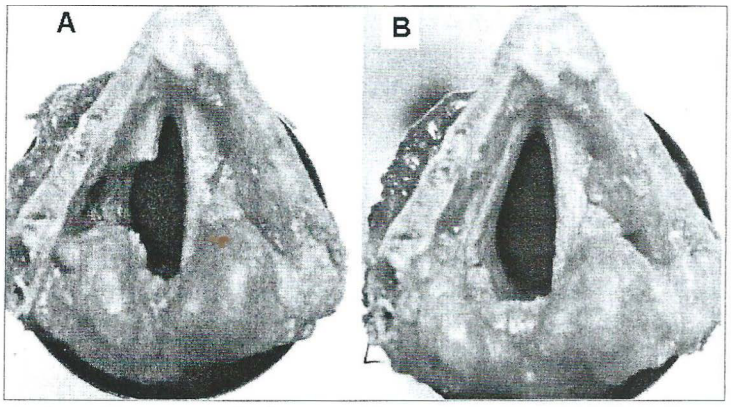
	Átlag (°)	SD +/-	Min. (°)	Max. (°)
Cadaver	10,67	4,4	3,35	21,0
VCL 1 öltés	30,46	7,45	15,56	47,63
VCL 2 öltés	30,92	5,99	20,82	43,4
S	47,22	11,09	33,86	79,89
EAL	50,24	8,34	28,86	73,0
A	10,79	4,59	5,34	20,8
TC	11,49	4,35	4,3	19,5

VCL: hangszalag laterofixatio, S: Schobel-műtét, EAL: endoszkópos arytenoid lateropexia, TC: transzverz chordotomia, A: aytenoidectomia

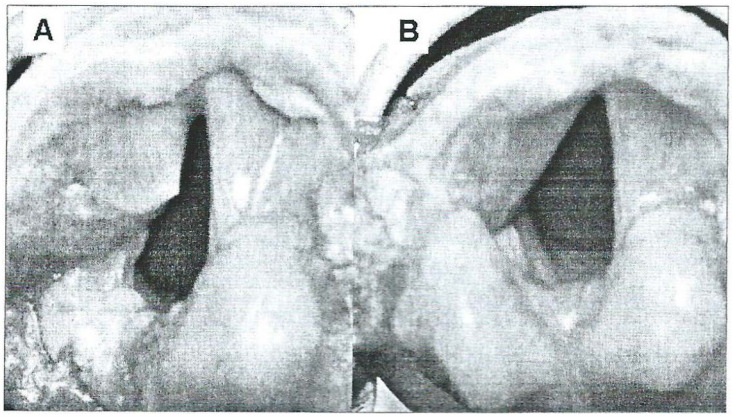
során a hátsó terület konfigurációja érdemben nem változik a műtét során, az irreverzibilis arytenoidectomia során nyerhető javulás jelentősen elmarad az EAL által biztosítottól, mivel a hangszalag helyzetében érdemleges lateralizáció nem történik (*3. táblázat*).

Megbeszélés

A hangréstágító műtétek cadaver gégéken történő összehasonlítására már korábban történtek vizsgálatok, azonban ezek megbízhatósága számos szempontból megkérdőjelezhető. *Eckel és Sittel* (5) a glottis síkjában készített fagyasztott makroszkópos metszeteket a chordotomia és arytenoidectomia elméleti hatásosságának pontos, számszerű összehasonlítására. Az időigényes, költséges módszer nem tett lehetővé nagy esetszámú vizsgálatokat, ami a gége anatómiájának nagy variabilitása miatt az eredmények korlátozott értékelhetőségéhez vezet. Módszerük további hiányossága, hogy a képletek több dimenzióban történő műtéti elmozdulásának horizontális vetülete nehezen elemezhető, illetve ugyanazon gégén a különböző módszerek hatása vethető össze.



3. ábra. Transzverz chodotomia (A) és EAL (B) képe



4. ábra. Arytenoidectomia (A) és EAL (B)

Az általunk kialakított, ma már egyszerűnek tekinthető digitális képértékelési morphometriai módszerrel ezek a technikai hiányosságok kiküszöbölhetőek. A standardizált helyzetben rögzített gége nagy felbontású fényképezőgéppel, jó minőségű optikával tört során a kép középső harmadában a torzulás elhanyagolható. A vizsgált műtét sebészi anatómiai sajátosságai, a megfelelő paraméterek könnyen, pontosan vizsgálhatók a gége hossztengelyére merőleges vetületen. A standardizált körülmények között, nagyszámú cadaver gégén végzett beavatkozás statisztikailag már figyelembe veszi az egyéni különbségek befolyásoló hatását. További előny, hogy a reverzibilis beavatkozások egymást követően elvégezhetők.

A hátsó commissurában *in vivo* végzett sebészi beavatkozás sikere nagymértékben függ attól, hogy a heg átvágása utáni ismételt összenövést hogyan tudjuk minimalizálni. Egyes szerzők a heg átvágása után kialakuló sebfelszínek lokális nyálkahártya-lebennyel történő fedését javasolják, ami kb. 30%-kal csökkenti a restenosis kialakulásának lehetőségét, azon-

3. táblázat

Eredmények statisztikai korrelációja

(+: a táblázat függőleges sorában szereplő műtéti eredmény nagyobb, mint a vízszintes sorban szereplő; –*: a táblázat függőleges sorában szereplő műtéti eredmény kisebb, mint a vízszintes sorban szereplő)

Középvonal – processus vocalis táv				
	VCL 1	VCL 2	S	EAL
Cadaver	–**	–**	–**	–**
VCL 1		NS	NS	–*
VCL 2	NS		NS	
S	NS	NS		NS
EAL	+*	+*	NS	
Hátsó commissura szöge				
	VCL 1	VCL 2	S	EAL
Cadaver	–**	–**	–**	–**
VCL 1		NS	–*	–*
VCL 2	NS		–*	–*
S	+*	+*		NS
EAL	+*	+*	NS	

VCL: hangszalag laterofixatio, S: Schobel-műtét, EAL: endoszkópos arytenoid lateropexia, NS: nem szignifikáns, *: $p<0,01$

ban a technika bonyolult és legtöbbször stent és tracheostoma együttes alkalmazását teszi szükségessé (7).

Elméletileg a hátsó commissurában kialakuló restenosis és a következményes hangszalag-medializáció annál kisebb lesz, minél tágabb, nyitottabb, stabilabb helyzetet tudunk kialakítani, és az esetleges restenosis okozta hangszalag medializáció hatása is kisebb lesz. A terület anatómiai jellemzői miatt ez az ideális helyzet a kannaporcok maximális inspirációs helyzetbe hozásával érhető el. A klinikai tapasztalatok mellett a cadaver gégéken végzett vizsgálataink egyértelműen alátámasztják, hogy ez a kannaporc hátrabillentésével, majd rögzítésével valósítható meg, szemben a hangszalag egyszerű oldalra húzásával. A cricoaryteniodealis izület mozgása ugyanis, szemben az egyszerű függőleges tengely körüli elfordulással (26), ami már elavult elképzelés, de sajnálatosan jelenleg is a hangszalag laterofixációs technikák elméleti alapja, lényegesen összetettebb, több tengely körüli billenéssel írható le (18, 27). A javasolt billentő manőverrel az EAL során a kellően mobilizált kannaporc a fiziológiás abdukciós helyzetbe hozható, és ebben a helyzetben végezhető el a lateropexia (20). Ez a magyarázata, hogy módszerünk sokkal jobb eredményt biztosít, mint a többi fonalhurokra épülő hangszalag lateralizációs technika. Mivel a klinikai gyakorlatban a beavatkozást két oldalon végezzük, a műtétek közti különbségek még markánsabban jelentkeznek. Nagy előnye az eljárásnak, hogy nem kell stentet alkalmazni és így nem kell fenntartani tracheostomát, továbbá teljes egészében megkímélhető a hangszalag fonációs felszíne, ami fontos a posztoperatív hangképzés szempontjából.

Az egy és két öltéssel elvégzett VCL elemzése során látható, hogy a posterior glottisban a második öltés további területet nem biztosít.

A külső behatolásból végzett S műtét klinikai eredményeit lényegesen jobbnak találtuk, ezek összevethetőek a sokkal kevésbé invazív EAL eredményeivel.

TC során nem észleltünk szignifikáns területnövekedést a posterior glottisban az alaphelyzet, a cadaver álláshoz képest. A TC légzést javító hatása egyértelműen a hangszalag állományának drasztikus csökkentéséből ered, ami a hangminőség jelentős romlásához vezet.

Az arytenoidectomia némileg tágabb viszonyokat hoz létre, mint a VCL, de az eredmények elmaradtak az EAL-hez képest. Ennél a beavatkozásnál a hangszalag helyzete nem változik, ami várhatóan kisebb légzésjavulást okoz. A heges környezetben végzett resectio után gyakoribb a restenosis, továbbá a kannaporc eltávolítása a funkció irreverzibilis károsodásához vezet.

Következtetés

Cadaver gégéken végzett vizsgálataink alátámasztják, hogy a kannaporc belégzési helyzete fonalhurokkal, illetve a lateropexia során alkalmazott megfelelő manőverekkel hatásosan létrehozható. Az így elért glottis konfiguráció a hátsó commissura hegesedés megoldására minden szempontból előnyösebb feltételeket biztosít, mint a korábbi endoszkópos módszerek.

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ZUSAMMENFASSUNG: *Einführung:* Zur Behandlung der Vernarbung der hinteren Kommissur führten wir in den vergangenen 10 Jahren in unserer Klinik eine neue endoskopische Operationsmethode ein, die nach Entfernung der Narben auf einer beidseitigen Lateropexie der beiden Kannaknorpel beruht. Um diesen Eingriff mit den früheren Operationstechniken objektiv vergleichen zu können, untersuchten wir die mit den unterschiedlichen Naht- und Fixatinstechniken erreichbaren Aenderungen an der hinteren Kommissur.
Methode: Die Messungen geschahen an 100 Kadaver-Kehlköpfen (50 männliche, 50 weibliche), an denen die unterschiedlichen Nahttechniken vorgenommen wurden: klassische Stimmband-Laterofixation (VCL) mit einer oder zwei Schlingen, endoskopische Arytenoid-Lateropexie (EAL), Schobel-Operation; anschließend wurden für den Operationserfolg wichtige Parameter mit digitaler Bildanalysen-Meßtechnik ausgewertet. Im zweiten Schritt beurteilten wir die zu erwartenden Ergebnisse der Arytenoidektomie und der transversalen Chordotomie (TZC) – vergleichend mit den obigen Meßmethoden.
Ergebnis: beim Vergleich zur Stimmbandstellung am Kadaver bieten alle auf Nahtschlingen beruhenden Techniken einen signifikanten Vorteil in der hinteren Kommissur, das beste Ergebnis brachten die EAL und die Schobel-Technik. Bei der VCL war kein Unterschied zwischen einer oder zwei Schlingen zu verzeichnen. Die Schobel-Technik und die EAL sicherten in allen Fällen bessere Parameter. Bei der TC fanden wir keine wesentliche Konfigurationsänderung, Die völlige Entfernung des Kannaknorpels führte zu sofortiger wesentlicher Erweiterung der hinteren Kommissur.
Besprechung: Unsere Untersuchungen an Kadaverkehlköpfen bestätigen, daß die Fixation des Kannaknorpels in einer der Einatmung entsprechenden Stellung die weiteste und opertionstechnisch günstigste Situation in der hinteren Kommissur garantiert. Auch die Arytenoidektomie sichert eine wesentliche Erweiterung der hinteren Kommissur, jedoch muß nach diesem Eingriff beim Lebenden mit Funktionsverlust gerechnet werden.
SCHLÜSSELWÖRTER: Arytenoid-Lateropexie, endoskopische Mikrochirurgie am Kehlkopf, Vernarbung der hintren Kommissur.

FÜL-, ORR-, GÉGEGYÓGYÁSZAT

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VI.

Új, fonalvezető eszköz az endoszkópos arytenoid lateropexia céljára
(A New Thread Guide Instrument for Endoscopic Arytenoid Lateropexy)

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A kétoldali hangszál-mozgásképtelenség (bilateral vocal cord immobility, BVCI) rendszerint másodlagosan, neuropathia, musculáris zavarok vagy mechanikus fixáció (MF) következtében alakul ki. Az okozott dyspnoe miatt, mely mérsékelttől nagy fokig terjedhet, általában sebészi beavatkozásra van szükség. Újabban külső feltárás helyett különféle endoszkópos eljárásokkal helyre lehet állítani a légutat kétoldali hangszálbénulásnál (bilateral vocal cord paralysis, BVCP), azonban a MF kezelése gyakran külső behatolást igényel (pl. laminotomia). A BVCP sokszor várható reverzibilitása további therápiás nehézséget jelent, mivel olyan technikára van szükség, amellyel a glottis fukncíója helyreállítható.

A szerzők régebben foglalkoznak a kérdéssel, korábban már beszámoltak sikeres esetekről, melyekben az aryporcot normális, abdukált helyzetbe lateralizálták endoszkópos varratokkal. Az eljárás előnyeit nem csak a BVCP-nél tapasztalták, hanem MF súlyos eseteiben is a crycoarytenoid ízület (crycoarytenoid joint, CAJ) megfelelő felszabadítása után.

Mivel ehhez a fonalhurkot hátrébb kell felhelyezni, ennek behelyezése gyakorlatilag lehetetlen kívülről bevezetett tűvel, mint ezt Ejnell eljárása írja. Ugyancsak nehéz a megoldás a Lichtenberger-féle eszközzel is, mert ezen a helyen a pajzsporc vaskosabb. Továbbá mindkét módszer problémája, hogy a fonalat át kell vezetni a szájüregen, ami fertőzésveszélyt jelent. Ezen nehézségek elkerülésére fejlesztették ki új eszközüket, mellyel biztonságosan, pontosan és gyorsan lehet elvégezni az endoszkópos arytenoid lateropexiát (endoscopic arytenoid lateropexy, EAL).

Anyag és módszer

Az endolaryngeális, fonalvezető eszköz (endolaryngeal thread guide instrument, ETGI) lényege a beépített, mozgatható, hajlított kés, hegyén egy nyílással, mely lehetővé teszi a fonal ki- és befelé történő átvezetését a nyak külső felszíne és a gége űrtere között. Az eszköz nyele vékony, merev acélcső, distalis végén meghajlítva úgy, hogy beleférjen egy középméretű laryngoszkópba. Ebben a csőben csúszkál egy hajlékony fémpálca, melynek proximális végén gyűrű van az operatőr hüvelykujja számára, disztális végén pedig egy hajlított penge, mely illeszkedik a nyél hajlított végébe. A penge a pálcára flexibilisen, de fixen van felerősítve, ami lehetővé teszi az erőteljes, előrehátra való mozgatását. A harmadik lényeges része a műszernek a markolat, mellyel az egészet irányítani lehet, mivel a nyél ehhez egy szorítócsavar segítségével csatlakozik a kellő irányba való beállítás végett. (Az eszközt elfogadta a Magyar Orvosi Műszerügyi Intézet.)

Alapfeltétel a jetlélegeztetéssel kombinált narkózis. Az eszközt Weerda vagy McIntosh laryngoscopon át vezetik be. Ha a hátsó glottis-stenosis hegkimetszésére is szükség van (MF), akkor egy maguk által tervezett, derékszögben hajlított, kasza alakú kést használnak a CAJ összenövéseinek átvágására, igény szerint kiegészítve CO_2-lézerrel. Általában a BVCP esetekben egyoldali EAL-t végeznek, az MF-nél pedig kétoldalit.

A beavatkozáshoz az ETGI-t laryngoscopon át vezetik be a glottis szintjéig. A mobilis vagy mobilizált kannaporcot hátra- és felfelé hajtják az eszköz végével, majd az addig behúzott pengét a processus vocalis alatt átnyomják a nyak külső felszínére, ahonnan a nyílásába belefűzött, dupla, fel nem szívódó fonalat visszahúzzák a gégébe. Ezután a kést a kannaporc felett ismét átnyomják a felszínre a fonállal együtt, melyet átvágva kivesznek a penge nyílásából. Ekkor már az eszköz eltávolítható. Az így keletkezett dupla hurkot kis bőrmetszés után megcsomózzák a m. sternohyoidon, ami által két fixáló hurok biztosítja az aryporc maximális, fiziológiás abdukcióját. Mindez kb. 5 perc alatt.

Utókezelés: Hátsó glottisszűkület (posterior glottic stenosis, PGS) esetében lokális mitomycin-C-t is javasolnak. A műtét után parenterális antibiotikum és szteroid ajánlott pár napra, valamint egyhetes beszédtilalom. Általában a kórházi tartózkodás három nap. A fonalak eltávolíthatók kb. nyolc hét múlva, ha a hátsó comissura áthámosodása befejeződött.

Betegek:

2005 és 2008 között 34 beteget (21 nő, 13 férfi) kezeltek BVCI miatt. Az utánkövetési idő 12 – 47 hónap (átlag 27 hó) volt, az életkor pedig 18 – 68 év (átlag 49 év). A BVCP csoportba 22 beteget soroltak: 18 pajzsmirígyműtéti szövődmény, egy crico-tracheális rezekció és három, nyelőcsőtumor által beszűrt nervus recurrens miatti paresis. A fennmaradó 12 eset MF volt, tíz PGS és két rheumatoid arthritis

(RA). A beavatkozás előtt a betegeket felvilágosították hangjuk várható rosszabbodásáról, mégis mind az EAL-t választott a tracheostoma vagy a „figyeljünk és várjunk" álláspont helyett.

Eredmények

Csupán két problémás esetük volt: egy RA-s, immunsuppressio alatt álló nőnél átmeneti, és egy nyelőcsőrákos, kemoterápiás férfinél végleges légcsőmetszést kellett végezni. Ezeket kivéve nem fordult elő sem jelentős postoperatív szövődmény, sem hangszál remedializáció. A lényegesen javult belégzési csúcs (peak inspiratory flow, PIF) az első, műtét utáni napon, és az egy évvel későbbi, csaknem megduplázódott érték igazolta az eljárás közvetlen és hosszú távú eredményességét.

Ami a fonációt illeti a 33 sikeresen kezelt beteg közül teljes hangszál-gyógyulást észleltek hat BVCP-nél (négy kétoldali, két egyoldali) és hat MF-nél. A hang-paramétereik a fixáló varrat eltávolítása után kifejezetten javultak, illetve teljesen normális minőségűek lettek. 13 BVCP beteg mutatott inkomplett javulást, melyet az addukciós kompenzáció hozott létre a nem-fixált oldalról. Három MF-nál a kétoldali EAL jelentős glottistágulást eredményezett, de az addukció nem állt vissza. Ezen utóbbi 16 betegnél hátsó zárási elégtelenség maradt fenn rekedtséggel, bár szociálisan elfogadhatóan. Két nagyfokú PGS és egy RA esetben viszont romlott az addukció súlyos dysphoniával. Két állandó BVCP-nél (egyik nyelőcsőtumor, a másik COPD-hoz társult chronikus laryngitis) az aphonia teljes maradt.

Megbeszélés

Egészséges esetekben abdukció alatt a processus vocalis oldalra történő csúszó mozgása társul egy felfelé és alkalmanként enyhén hátrafelé mutató mozgással, mialatt az arytenoid porc oldalra és felfelé fordul a cricoid porc felszínén. Ez a kulcsa a valóban hatásos és egyszerű lateralizáló varrat behelyezésének, mert nyilvánvaló, hogy a fixáló varrat ellen való alsó ellenállás akkor lép fel, ha az ízület a természetes útján mozog. Ez a pozíció egy szignifikánsabb glottistágulatot eredményez, mint a szokásos, duplahurkos (Lichtenberger-féle) hangszál-laterofixáció. Ezt a morfometriás méréseink során állapítotttuk meg, melyeket 60 kadáver gégén végeztünk el. Sőt ez magyarázza a PIF nyereséget a BVCP betegeknél (45%-os javulás), valamint azt, hogy a hurkok a porc stabil felszínén maradnak, nem tudnak elcsúszni, ezáltal bevágni a hangszálat. A korábbi módszereknél éppen a huroknak ez a hátrább való behelyezése volt nehézkes. Az is figyelemre méltó, hogy az ETGI folyamatos varratvezetésre ad lehetőséget, nincs szükség az eszköz ismételt, külső befűzésére – mint a Lichtenberger-féle eszköznél. Az Ejnell-féle eljárás pedig jóval hosszabb időt igényel a pajzsporc széles feltárása miatt. Szerzőink kijelentik, hogy az EALhoz szükséges, pontos hurokképzés gyorsabb és biztosabb az ETGI segítségével.

További előnyök:

1. könnyen elvégezhető;
2. az egyetlen manőverrel képzett dupla hurok amellett, hogy fokozza a hatékonyságot, csökkenti a remedializáció kockázatát;
3. a fonal a fertőtlenített gégeűrtéren belül és a bőrön át mozog, ezáltal csökken a fertőzés veszélye;
4. a módszer kihasználja az abdukció normál mechanizmusát, így kevesebb a lehetséges kontraindikáció. A BVCI válogatás nélküli eseteiben fellépett két szövődmény az immunszuppresszió-nak tudható be. Légúti fertőzés jelenthet ellenjavallatot.

Végkövetkeztetés

Az EAL minimálisan invazív, hatékony és dinamikus megoldás a legtöbb BVCI esetben. Az ETGI-t kifejezetten erre a módszerre fejlesztették ki, mely nagyban megkönnyíti az eljárást. A beavatkozás egyszerűsége, a reverzibilitás nagy foka, a gégefunkció könnyen kimutatható javulása, és a jó, hosszú távú eredmények leegyszerűsítik ezeknek a betegeknek a kezelését, akiknél sokszor jatrogén aetiológia áll fenn.

Referáló megjegyzése: A magyar szerzőknek a legtekintélyesebb, külföldi folyóiratban megjelent közleményét azért tartottam referálásra érdemesnek, mert ígéretes, új eljárást és eszközt mutat be, mely méltán illik a jeles hazai gégészeti hagyományok sorába. Várjuk, hogy a szerzők itthon is mutassák be még nagyobb anyagon módszerüket.

Sarkady László dr.
Budapest

VII.

A NEW ENDOLARYNGEAL THREAD GUIDE INSTRUMENT FOR ARYTENOID LATEROPEXY

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SUMMARY

Objectives: The varied etiology of bilateral vocal fold immobility (bVFI) requires a wide range of surgical approaches. A new endolaryngeal thread guide instrument (ETGI) is presented here for a minimally invasive endoscopic lateropexy of the arytenoid cartilage, which may serve as a basis for a simple solution of main types of bVFI.

Study Design: Prospective study of 34 bVFI patients who underwent surgery (22 paralyses, 10 posterior glottic stenoses, and 2 rheumatoid ankyloses).

Methods: The ETGI is based on a built-in movable curved blade with a hole at its tip in order to guide a thread in and out again between the skin and the laryngeal cavity. The loops formed around the arytenoid cartilage cause abduction. In cases of fixations, the cricoarytenoid joints were properly mobilized as a first step with a combination of cold technique and CO_2 laser.

Results: As spirometric tests proved, 32 patients achieved improved breathing ability. One temporary tracheostomy was necessary and 1 patient with ongoing radiotherapy could not be decannulated. Subjectively, twelve patients' voices improved or approximated normal quality due to complete vocal cord recoveries on at least one side after lateropexy was ceased. Incomplete recovery with more or less hoarse voice was observed in 17 cases. Five patients had permanent complete laryngeal paresis associated with severe aphonia.

Conclusions: Combined with simple and readily avaliable methods,

endoscopic arytenoid lateropexy is an effective solution for bVFIs with various etiologies. The ETGI facilitates this procedure with rapid and safe creation of fixating loops at the proper position.

Key Words: arytenoid lateropexy, laryngeal microsurgery, laryngeal rheumatoid arthritis, vocal cord immobility.

INTRODUCTION

Vocal fold immobility (VFI) is a collective term used to describe vocal folds that are restricted secondary to mechanical fixation, neuropathy or muscular disorders (1). Nowadays posterior glottic stenosis (PGS) due to prolonged intobation has become the most common cause of mechanical vocal cord fixation (MVF) (2), but this may result from many other ankylotic processes in the cricoarytenoid joint (1). The more common vocal cord paralysis (VCP) due to neurogenic immobility may occur most frequently after recurrent laryngeal nerve injury during thyroid surgery (3).

In case of bilateral VFI the magnitude of the dyspnea depends on the position of the vocal folds and on the cardiopulmonary reserve, but most patients require surgical treatment. From the aspect of breathing the recently commonly used various types of endoscopic treatment modalities, as arytenoidectomy and/or cordotomy (4,5) may provide an appropriate solution for paralytic bVFIs, but the treatment of mechanical fixations often means a difficult question and often necessitates external approach with temporary tracheotomy and stenting (6). A further problem of making the right decision is that in mechanical fixations the motor innervation is generally intact and the paralytic cases are often potentially reversible, so surgical techniques based on any kind of resection of the glottic structures mean a sacrifice of laryngeal function to some extent (3). These facts point out that making the right choice from the various therapeutic options is often based on compromises, and the optimized care of patients must rely on multiple, often inconvenient diagnostic interventions.

Our earlier studies (2, 3) demonstrated that the direct endoscopic

arytenoid cartilage lateropexy to normal abducted position by a suture loop ensures an immediate adequate airway with the possibility of function recovery even in cases of severe stenoses. This minimally invasive technique may therefore simplify VFI patient care; hence, the diagnosis of and solution to dyspnea can be brought about with one endoscopic procedure. Nevertheless, the proper endoscopic insertion of the fixating loop is often difficult with the earlier methods because of the peculiarity of laryngeal anatomy. We hereby present an alternative way of suture loop creation by the prototype of a new endolaryngeal thread guide instrument, which is designed for a safe and simple endoscopic arytenoid lateropexy

METHODS AND PATIENTS

Endolaryngeal thread guide instrument (ETGI) (Figure. 1a)

The principle of the ETGI is based on a built-in movable curved blade with a hole at its tip (Figure. 1b) in order to guide a thread in or out between the outer surface of the neck and the laryngeal cavity. The stem of the instrument is a rigid steel pipe which is curved at its blade-holding distal end in order to fit into mid-sized closed laryngoscopes. The second part is a rod placed in the sheath mentioned with a freely rotating finger clip at the proximal end and a curved blade which is appropriately inflected to the curvature of the stem. The fixed but flexible connection between the blade and the rod ensures a smooth and forceful in or out movement of the blade inserted into the tip of the instrument (Figure 1 A and B) by pulling or pushing the finger clip with the thumb. The third part is an ergonomic handle, which also serves as a shaft to hold the instrument in a straight position. The direction of the curved part can be changed by turning the stem in the desired direction and fixed to the shaft with a binding piece and a bleed clamping screw.

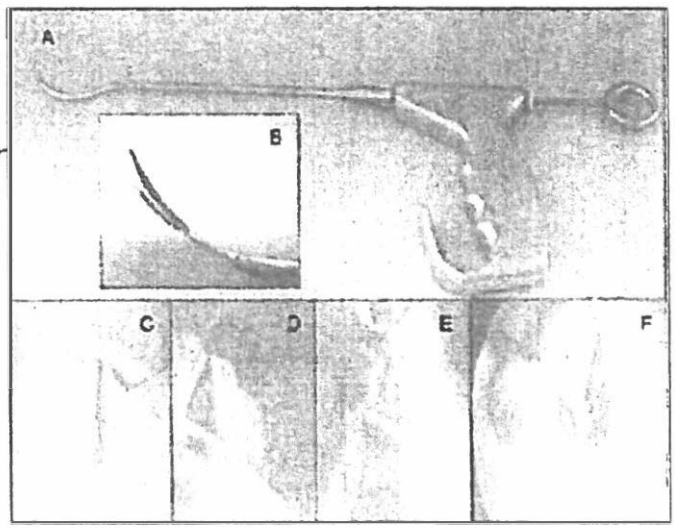
Surgical procedure and postoperative care

The procedure is performed under general anesthesia. Supraglottic jet ventilation is suggested. For the sake of maneuverability, the larynx is exposed with a Weerda laryngoscope (Figure 1C-F). Afterwards, the mobility of the cricoarytenoid joints is examined. In cases of joint immobility CO_2 laser and a strong, right-angled sabre-shaped scythe designed by our team (2) is used for dividing the adhesions between the arytenoids and/or the cricoid cartilage

The ETGI is led through the laryngoscope to the glottic level. The arytenoid cartilage is tilted backwards and upwards with the end of the instrument, and then the built-in curved blade is pushed through under the vocal process out to the surface of the neck (Figure 1D). After this, a nonabsorbable thread (Prolene 1.0) is laced by an assistant surgeon up to its midpoint through the hole at the tip of the blade. The thread folded this way is pulled back with the blade to the laryngeal cavity. After a repeated tilting of the arytenoid cartilage, the blade is pushed out with the thread above the vocal process (Figure 1E). Then the assistant surgeon removes the double-folded thread with a cut from the blade. Following this the blade is pulled back and the ETGI can be removed. A small skin incision (appr. 5 mm) is made and the ends of the thread are withdrawn by a Jansen hook through it to the surface of the sternohyoid muscle, and the corresponding ends are knotted above it. This simple and fast procedure enables the creation of *two* fixating loops in one step in the appropriate spot to approximate the maximal physiological abduction of the arytenoid cartilage (Figures 1F).

Figure 1.

The ETGI and its operation demonstrated on a 62-year woman with bilateral VCP



In the peri- and postoperative period the patients are administered antibiotics and corticosteroids. The fixating sutures can be removed via a small skin reincision if vocal cord recovery is detected on at least one side.

Patients were followed up every 2 weeks during the first 2 months, then monthly until the end of the second year. Their laryngeal status was examined by videolaryngoscopy and by spirometric measurements. Peak inspiratory flow (PIF) was documented preoperatively. This was repeated for all patients after surgery (1–4 days) and finally at the end of the first postoperative year.

Patients

From February 2005 to November 2008 34 patients (21 females and 13 males) were diagnosed and treated by ETGI for bilateral VFI at our department. The ages ranged from 18 to 68 years with a mean of 49 years. There were 22 patients in the VCP group. Bilateral VFI was observed after thyroid surgery in 18 cases and after a cricotracheal resection in 1 patient. Bilateral tumor infiltration of the recurrent laryngeal nerves was the causing factor in another 3 cases.

Ten of twelve cases of MVF considered being PGS developed after prolonged intubation. The remaining 2 patients had bilateral ankylosis due to the laryngeal involvement of rheumatoid arthritis. 4 patients wore cannula and 2 were intubated upon admittance, the others had moderate to severe stridor at rest and severe stridor on exertion.

RESULTS

The ETGI enabled us to create the fixating loops in the desired position in all patients without any complications. In all except 2 patients, breathing improved immediately and considerably after surgery. One patient with

rheumatoid arthritis required a tracheotomy for 2 weeks for an uncontrollable edema. The cannula became permanent in a VCP case due to an infiltrating tumor in which the arytenoid lateropexy had been performed during ongoing radiotherapy. Apart from these, the increase of postoperative PIF values in both groups supports the immediate efficacy of the procedure. The approximately doubled final values also confirm the long-term reliability (Table I). This further increase may be explained by the complete or partial vocal fold recovery detected in many patients and by the improvement in their overall health. Considerable restenosis occurred in only severe PGS patients. Even in this case breathing was adequate at rest with stridor presenting only on effort. Subjectively, the breathing of the patients with rheumatoid arthritis also normalized, but the progress in their spirometric values was not so remarkable.

Subjectively, twelve patients' voices improved or approximated normal quality due to complete vocal cord recoveries on at least one side after lateropexy was ceased. Incomplete recovery with more or less hoarse voice was observed in 17 cases. Five patients retained permanent complete laryngeal paresis associate with severe aphonia.

Table I. Early and late spirometric results.

**1 patient with cannula, 2 intubated patients, and 3 patients with severe suffocation were not measured. †3 patients with cannula and 2 patients with severe suffocation were not measured. ‡Temporary tracheostomy for 2 weeks. × 1 patient was not decannulated. ♦At least 8 weeks after the releasing of the vocal folds or at least 6 months after the operation in the case of permanent VFI. PIF = peak inspiratory flow; SD = standard deviation*

Bilateral recurrent nerve paralyses (n=22; female/male=17/5)				
	Age (years)	PIF (l/s) Preop.*	Postop.×	Final results◆
Mean	53.0	1.47	2.39	2.79
Min./max.	26/78	0.5/2.12	0.78/3.62	1.75/4.0
SD	±12.4	±0.42	±0.78	±0.67

Mechanical fixations				
Posterior glottic stenoses (n= 10; female/male=3/7)				
	Age (years)	PIF (l/s) Preop.†	Postop.	Final results◆
Mean	45	1.77	2.72	4.04
Min./max.	28/66	1.25/2.37	1.75/4.37	3.12/5.62
SD	±15.65	±0.45	±0.83	±0.98
Rheumatoid arthritis with ankylosis (n= 2; female/male=1/1)				
	Sex/Age (years)	PIF (l/s) Preop.	Postop.	12th month
	female/49	1.15	‡1.87	1.75
	male/18	1.85	2.25	2.37

DISCUSSION

The simple rotation around the vertical axis, which is generally considered to be the theoretical basis for simple *vocal cord laterofixation* techniques (7, 8), exists only in standard anatomy textbooks (9) but is not found in investigations on the subject. A helical axis close to the vertical has been suggested (10, 11). Wang (11) has convincingly demonstrated that during abduction the lateral sliding motion of the vocal process is simultaneously accompanied by an upward and occasionally slightly posterior movement with the arytenoid cartilage turning laterally and upward on the cricoid cartilage facet. It is obvious that the lowest resistance against the fixating sutures arises if the joint was moved its natural way. With our surgical refinement technique a thoroughly mobilized (2, 3) arytenoid cartilage can be brought endoscopically to a physiologically abducted position with the described tilting maneuver as by the earlier effective external arytenoidopexy procedures (10).

vibration may badly affect voice production. This can also be avoided if the loops stay on the arytenoid cartilage. The preservation of the fine laryngeal structures ensures the reversibility of the procedure to a large extent .

CONCLUSION

Endoscopic arytenoid lateropexy, which is designed by the new anatomical observations of the cricoarytenoid joint, may serve as a minimally invasive, effective, dynamic primary solution for most bilateral VFI. Commercial availability of an instrument specially designed for this procedure, as the ETGI with the described new way of thread guiding, can facilitate this procedure with the rapid and safe creation of fixating loops at the proper position. The simple surgical procedure, the great extent of reversibility, the easily detectable laryngeal function recovery, and the good functional results may simplify the management of these patients with usually iatrogenic etiology.

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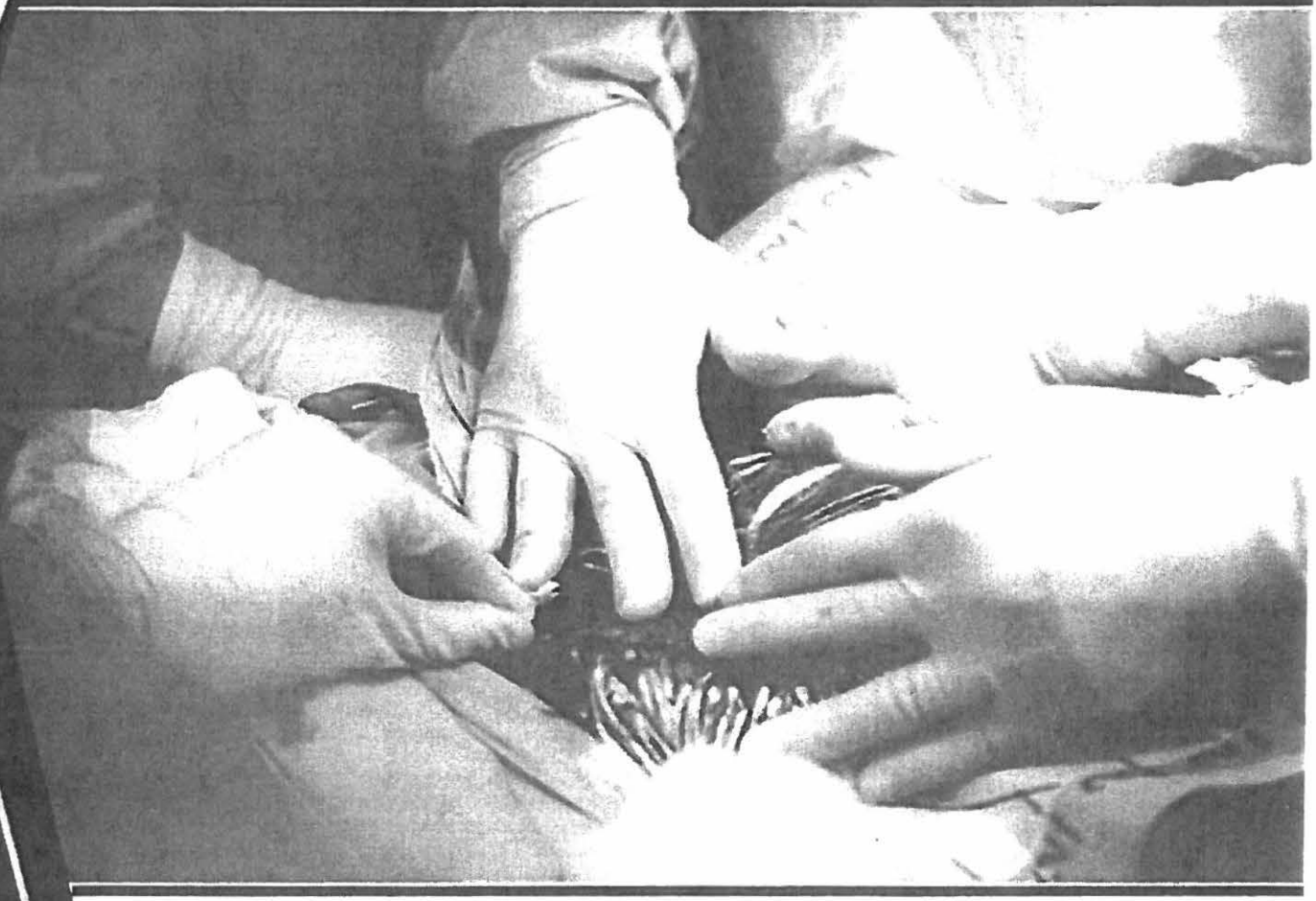

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VIII.

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(igazgató: Jóri József dr. egyetemi tanár)

A cricoarytenoidalis izület mozgásának vizsgálata digitalis képelemzéssel

Rovó László dr., Madani Shahram dr., Tóth Ferenc, Kiss József Géza dr.*

ÖSSZEFOGLALÁS: A circoarytenoidalis izület pontos anatómiája és működése napjainkban is vitatott kérdés. Az izületek közti méretbeli és strukturális, gyakran egy gégén belül észlelhető különbségek megnehezítik a domináló mozgásforma felismerését a többségében kis esetszámon történt, az anatómiai részletekre koncentráló vizsgálatok alapján. A gégesebészet fejlődése, az eddig szinte csak elméleti problémaként kezelt kérdésnek jól körülírt, gyakorlati jelentőséget ad. A szerzők 100 gégét vizsgálva, a kannaporcok felülnézeti síkban történő elmozdulási értékeit képdigitalizációs technikával átlagolták. A kapott elmozdulási mintázatot összehasonlították a három leggyakrabban feltételezett mozgásforma, a rotáció (vertikális tengelykörüli forgás), az oldalirányú csúszás, illetve billenés (az izületen áthaladó vízszintes tengely körüli elfordulás) alapján várható mintázattal. Az eredmények alapján az utóbbi mozgásforma dominál a gége mozgása során, ami jól egyeztethető az izület legújabb anatómiai vizsgálatainak következtetéseivel is. A kannaporc és a processus vocalis háromdimenziós rendszerben történő mozgása egy határozott izületi mechanizmushoz kapcsolható. Ennek ismerete alapvető a hangszalag helyzetét korrigáló, medializációs, vagy laterofixatiós műtéteknél a hosszantartó jó eredmények biztosításához.

KULCSSZAVAK: cricoarytenoidalis izület, digitális képelemzés hangréstágító műtét, hangszalag-medializáció, hangszalagmozgás

SUMMARY: The exact anatomy and workings of the cricoarytenoid joint is still a matter of debate today. Due to the small number of study cases and the investigations concentrating mainly on anatomical details, the anatomical and structural differences between the cricoarytenoid joints make the detection of the dominant type of motion difficult. The development of laryngeal surgery makes the hilter to theoretical question a very practical one. The authors averaged the motion values of the arytenoid cartilages in top view plain using a digital picture analyzing method. The movement pattern thus received was compared to the three most often assumed forms of motion: rotation, sidewise sliding and rocking. According to the results the latter is the dominant form of motion, and this correlates with the newest results of anatomical investigations. Understanding the motion of the arytenoid cartilage and the vocal process is of utmost importance in vocal cord medialization and lateralization procedures.

Keywords: cricoarytenoid joint, digital picture analyzing, vocal cord lateralization, vocal cord medialization, vocal cord motion

Bevezetés

A circoarytenoidalis izület anatómiája és működése napjainkig vitatott kérdés (13, 20, 21, 29). *Galenus* (i.e. 201–130) a gége zárását és nyitását a kannaporcnak a gyűrűporc izületi felszínén történő medialis és lateralis csúszásával magyarázta (6). *Willis* 1829-ben az izület működését a kannaporc előre, illetve hátra billenéseként értelmezte (30). 1907-ben *Morris és Mcmurrich* (10) és tőlük függetlenül *Piersol* (14) három különálló mozgás, – előre-, illetve hátradőlés, kifelé és befelé történő csúszás, valamint egy függőleges tengely körüli forgás, illetve csavarodás – kombinációjának írta le. A közismert, az izület mozgását egyszerű vertikális tengely körüli elfordulással magyarázó elmélet, a nemzetközi irodalmi adatok szerint *Negus*-tól (1929) származik (12), bár *Navratil* az 1887-ben megjelent „Gégebetegségek története" című könyvében már ezt a mechanizmust tartja helyesnek (11). Ezt követően egészen a legutóbbi időkig (2) ez a feltételezett mozgásforma található meg legtöbb nemzetközi és hazai anatómiai (8, 25) és gégészeti szakkönyvben (26). *Sonneson* 1969-ben visszatért *Willis* elméletéhez, és

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a cricoarytenoidalis izületet, a gyűrűporc mediansagittalis tengelyéhez képest ferde, egytengelyű hengerizületként (24) értelmezi. 1961-ben *Von Leden és Moore* (28) az izületet egy „sekély gömbizületként" definiálta, melyben előre- és hátradőlés, az alsó izületi felszín hossztengelyén történő csúszás, és limitált forgás történik. 1966-ban *Ardran és Kemp* (1) radiológiai vizsgálatokkal „in vivo" megállapította, hogy az abductió során a kannaporc kb. 30–45 fokkal hátrafelé billen az adductió helyzetéhez képest. 1975-ben *Fink* (4) gyakorlatilag visszatér *Galenus* elképzeléséhez, kiegészítve azt a rotáció lehetőségével.

Ezek, az egymásnak többé-kevésbé ellentmondó elméletek, általában a gégetükri kép értelmezése, és többnyire kisszámú anatómiai preparátumon végzett vizsgálatok, – pl. passzív mozgatás, vagy a belső gégeizmok izolált elektromos stimulációja – alapján születtek. A cricoarytenoidalis izületet borító lágyrészek és az izület rejtett helyzete a közvetlen vizsgálatot nem teszik lehetővé. Az izületek közti méretbeli és strukturális, gyakran egy gégén belül is észlelt különbségek (23) is megnehezítik a domináló mozgásforma felismerését, a többségében kis esetszámon történt vizsgálatok alapján. Ez magyarázhatja azt a tényt, miszerint olyan alapvető kérdések sem tisztázódtak egyértelműen, hogy az izületi felszínek egymáshoz való viszonya a mozgás különböző fázisaiban milyen (4, 23, 28, 30).

A modern gégesebészet fejlődése, a különböző hangszalag medializációs illetve laterofixációs technikák alkalmazása az egy-, illetve kétoldali hangszalagbénulásnál, az eddig szinte csak elméleti problémaként kezelt kérdésnek jól körülírt, gyakorlati jelentőséget ad. Nagy esetszámon végzett endoszkópos, képdigitalizációs technikával feldolgozott, a gégész „szemszögéből" végzett felvételek értékelésével és átlagolásával megállapítható a kannaporc helyzetének változása ab-, és adductió során. Az eredményt összevetve a modern anatómiai vizsgálatok következtetéseivel eldönthető, hogy mi a legvalószínűbb mozgás a cricoarytenoidalis izületben.

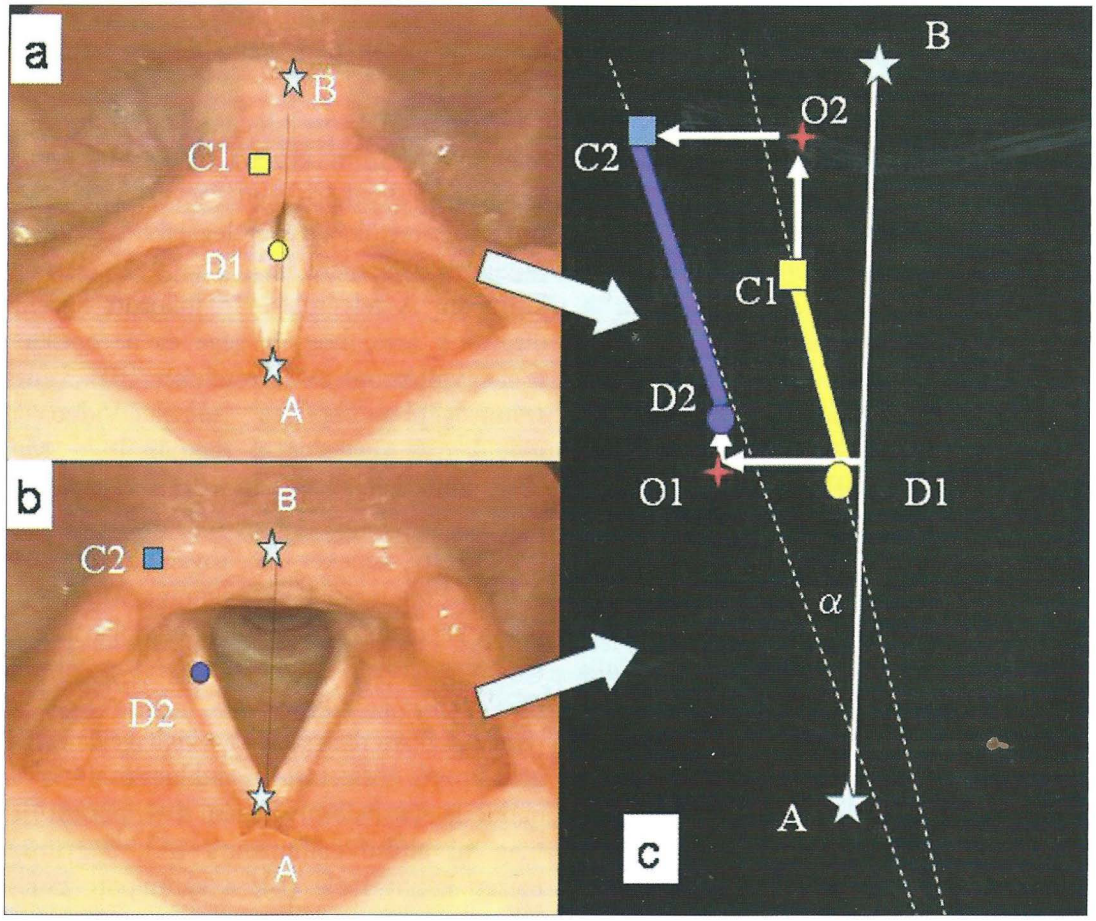
Anyag, módszer

A vizsgálat során 17 és 67 év közötti, ép gégéjű, 50 férfi és 50 női önkéntes gégemozgását elemeztük. Az átlagéletkor 45 év, előzőleg gégeműtétük vagy a gége integritását befolyásoló betegségük nem volt. További 13 személyt, a megfelelő együttműködés hiánya, az anatómiai viszonyok (pl. ómega epiglottis), vagy a vizsgált anatómiai képletek nem kellő felismerhetősége miatt zártunk ki.

A garat 10%-os lidocainoldattal történt érzéstelenítése után a középvonalban bevezetett 70°-os Storz-endoszkóp segítségével SVHS videószalagra rögzítettük a gégét legalább 3 halk „í" hang (adductió) és mély belégzés (abductió) váltakozó fázisában. A felvétel során fokozott figyelmet fordítottunk arra, hogy a gége és az optika helyzete ne változzon. A felvételeket IBM Pentium III számítógépbe épített miro Video DC-30 videókártya segítségével digitalizáltuk. Mindegyik gége adductióját és a legjobb abductiós helyzetének egy-egy képét külön rögzítettük, tároltuk. Az így nyert képeket a továbbiakban Microsoft Adobe Premier 5.1 c, valamint Microsoft Power Point képelemző programokkal dolgoztuk fel és a kapott adatokat Microsoft Excel programmal értékeltük.

Minden esetben a jobb oldali gégemozgást vizsgáltuk. Az összetartozó adductió (*1. a ábra*) és abductió (*1. b ábra*) képén 4–4 pontot jelöltünk meg: az elülső commissura (A); a gyűrűporc lemezének hátsó éle (B); a kannaporc csúcsát reprezentáló cartilago corniculata (C1, C2); a processus vocalisok (D1, D2). Ezek a pontok minden vizsgált esetben, olykor lassítással ugyan, de biztonsággal felismerhetőek voltak. A felvételek során egyértelmű volt, hogy az A és B pont helyzete lényegesen nem változik, tehát együtt alkalmas a különböző mozgásfázisok referenciapontjának. Ezek felhasználásával az adductió és az abductió képeit egymásra vetítettük, majd az alapképeket eltüntettük. Az endoszkópos technika nem teszi lehetővé az elmozdulás értékeinek pontos, számszerű meghatározását, de jól leírja ezek felülnézeti síkra történő vetületváltozásának *arányát és irányát* az egy gégében állandónak tekintett AB szakaszhoz képest. A különböző gégék közti anatómiai méretkülönbségek miatt, a kannaporcok mozgása különben sem vethető össze közvetlenül, ezért az átlagolhatóság érdekében, a vektoralgebrában használt normalizálás módszerét alkalmaztuk (5). A fenti módon mért viszonylagos elmozdulási értékeket minden esetben úgy felnagyítottuk, hogy minden AB szakasz 10 cm-es legyen (a jobb vizualizációs megértés érdekében), így a különböző kannaporcok elmozdulásának aránya összehasonlíthatóvá, statisztikailag feldolgozhatóvá vált.

Az így kapott ábrán (*1. c ábra*) jól vizsgálható az adductióból abductióba kerülő kannaporc fe-



1. ábra: 29 éves nő átlagos izületi mozgást jól reprezentáló gégéje. A jobb kannaporc felülnézeti síkra történő vetület változása a gége zárt (a), és nyitott (b) helyzetében; c: a két helyzet egymásra vetítésével kialakított, felnagyított geometriai ábra; szürke csillagok: a referenciapontként használt elülső commissura (A) és a gyűrűporc hátsó élének közepe (B), C1, C2: a kannaporc csúcsán elhelyezkedő cartilago corniculata D1, D2: a processus vocalis a gége nyitott, ill. zárt helyzetében

lülnézeti síkra történő vetületváltozása (C1D1 és C2D2 szakasz). Az általuk meghatározott egyenesek által bezárt szög (α): a függőleges tengely körüli esetleges elfordulás (alfa pozitív: ha az abdukció során a kannaporc vetülete kifelé fordult). A processus vocalis és a kannaporc csúcsának vetületi elmozdulási vektora is meghatározható a gége median-sagittalis tengelyével (AB szakasz által kijelölt egyenes) párhuzamos (O1D2, C1O2 pozitív, ha hátrafelé, a B pont felé mutat) és az erre merőleges (D1O1, C2O2 pozitív: ha az irány lateralis irányba mutat) vektorok összegével. A kannaporc vetületváltozását egymintás t-próbával, a nemek közti különbségeket kétmintás t-próbával vizsgáltuk.

Eredmények

Abductióban a kannaporc vetülete szignifikánsan ($P=1{,}32 \times 10^{-15}$) nagyobb, mint adductiónál (C2D2–C1D1>0) ami a kannaporc billenését bizonyítja (1. *táblázat*). A két vetület két, határozottan megkülönböztethető egyenest határoz meg. A két egyenes szöge (a felülnézeti síkra vetített elfordulási szög) férfiaknál 2,78°, a nőknél –2,47°, az összesített átlag –0,12°, tehát a két egyenes gyakorlatilag párhuzamos! A processus vocalis jelentős lateralis elmozdulás mellett kismértékben hátrafelé mozdul, a kannaporc csúcsa eközben nagyobb mértékben mozdul hátrafelé, és megközelítőleg a processus vocalisszal azonos mértékben lateralis irányba. Az abdukció során a kannaporc vetülete tehát hosszabb lesz, hátrébb és jelentősebben lateralis irányba kerül, szinte párhuzamosan az adductió vetületével. A szögeknél, az elmozdulási vektoroknál szignifikáns nemi eltérést nem találtunk. A vizsgált tényezőknél feltűnően nagy volt az értékek szórása.

Megbeszélés

A huszadik század második felében végzett klasszikus anatómiai tanulmányok, melyek közül esetszám tekintetében kiemelkednek *Sellars és Keen* 45 gégén végzett mérései (23), részleteiben is tisztázták a cricoarytenoidalis izület felépítésé-

1. táblázat

A 100 vizsgált gége alapján a kannaporc felülnézeti vetületváltozásának átlagos szögelfordulása és elmozdulási értékei

(az értékek cm-ben értendők, ha az AB szakaszt 10 cm-esnek tekintjük; jelölések az 1.c ábra alapján, részletes magyarázat a szövegben)

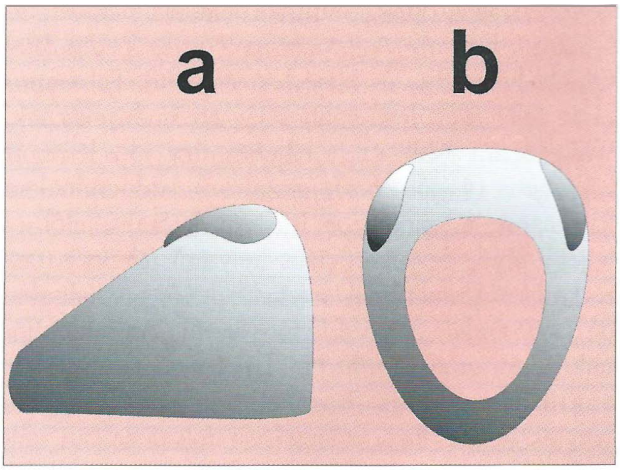
	C1D1	C2D2	C1O2	O2C2	D1O1	O1D2	CD-C1D1	α(o)
nők átlaga	3,32	4,05	1,66	2,07	2,04	0,96	0,73	–2,47
nők szórása	0,86	0,98	0,99	1,01	0,71	0,58	0,76	13,81
férfiak átlaga	3,12	3,98	1,64	2,42	2,18	0,95	0,86	2,78
férfiak szórása	0,75	0,96	1,28	1,22	0,74	1,14	0,93	17,87
ÖSSZÁTLAG	**3,22**	**4,02**	**1,62**	**2,26**	**2,12**	**0,93**	**0,80**	**–0,12**
ÖSSZSZÓRÁS	**0,83**	**0,98**	**1,13**	**1,12**	**0,70**	**0,90**	**0,85**	**15,95**

Napjainkban *Neuman és mtsai* (13) 8 cadavergégén CT-vel, *Wang* (29) 7 cadaver gégén a tér 3 irányából röntgenátvilágítóval készített videófelvételek elemzésével próbálták pontosítani az izületben történő 3 dimenziós mozgást. *Selbie és mtsai* (21) két férfigége izületi felszíneinek MRI segítségével történt digitalizálásával tettek kísérletet a lehetséges mozgástengelyek számítógépes modellezésére.

A cricoarytenoidalis izület a kannaporc és a gyűrűporc között helyezkedik el. A gyűrűporc pecsétjén lévő izületi felszín hosszabbik tengelye 5,4–9 mm, átlagosan 7,4 mm, ami a median-sagitalis tengellyel, általában a gyűrűporc pecsétje felé mutató 30–60°-os szöget zár be (9, 29), de néha azzal párhuzamos is lehet (23). Az izületi felszín előrefelé inkább a gyűrűporc felső felszínén helyezkedik el, majd hátrafelé az oldalsó felszín felé fordul át (29). Oldalnézetből tehát a szélesebb felével hátrafelé néző, felülről pedig előrefelé néző vízcsepphez hasonlítható (*2. ábra*). Az izületi felszín területe hátul oldalt nagyobb és laposabb (23), mint a felső-elülső. A harántátmérő a felszín egész hosszában konvex, legnagyobb szélessége 3–5,7 mm, átlagosan 4,2 mm. A kétoldali izületi felszín, sőt a gyűrűporc két oldala között is számos esetben jelentős aszimmetria mutatható ki (23). A kannaporcon alul található, hosszabbik átmérőjében konkáv izületi felszín, a processus vocalisra is kiterjed. A rövidebbik átmérőnek megfelelő felszín viszonylag lapos (9) és párhuzamos (22) a kb. 2,5 mm-rel hosszabb cricoideus izületi felszín hosszabbik átmérőjével. A hosszabbik, konkáv átmérőjével fekszik fel a cricoideus felszín rövidebb, convex tengelyére. A processus vocalis a kannaporc izületi felszínének középpontjához képest medialisan helyezkedik el, és hátrafelé mutató hegyesszöget zár be az izület h ezért a processus vocalis többékevésbé sagittalis helyzetű.

A laza izületi tok az izületi felszínek peremén ered, és tapad (8, 16, 22, 29). A tokot egy vastag, külső, az izülettől medialisan a gyűrűporc medialis éléről eredő, a kannaporc középmagasságáig legyező alakban hátul-felül, elől-alul, néha határozottan kettéválva tapadó szalag, a ligamentum cricoarytenoidale erősíti. *Wang* (29) két további, az izületi tok megerősödésének tartható kis szalagot ír le. A hátsó a ligamentum cricoarytenoidaletól kissé laterálisan helyezkedik el, míg az elülső a conus elasticus leghátsó rostjai alól ered és a ligamentum cricoarytenoidale legelülső-alsó rostjai alatt, a kannaporcon tapad.

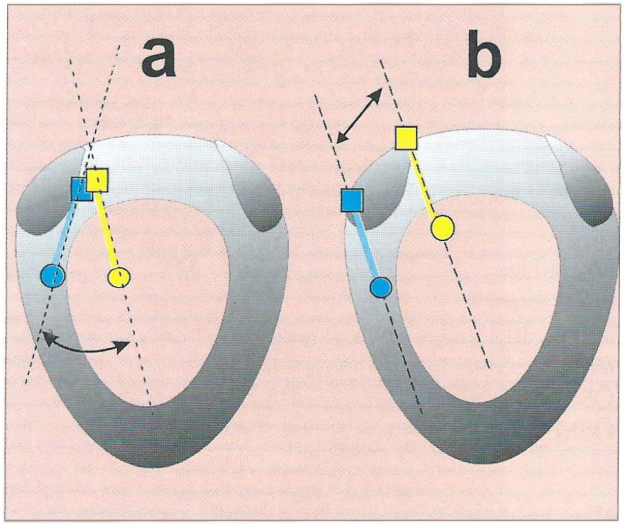
A kannaporc háromdimenziós térben mozog. Vizsgálataink során ebből csak a két, a felülnézeti síkra vonatkozó változót vizsgálhattuk, ezért a mozgások pontos, számszerű elemzése így nem lehetséges. Az általunk mért vetületi értékeket azonban összevetve az izület anatómiai konfigurációjával, az izületben történő mozgás fő tendenciái tisztázhatóak. Az eddigi elméletek 3 fő mozgásforma önálló, vagy kombinált jelenlétét feltételezik: a felülnézeti tengelyre többé-kevésbé me-



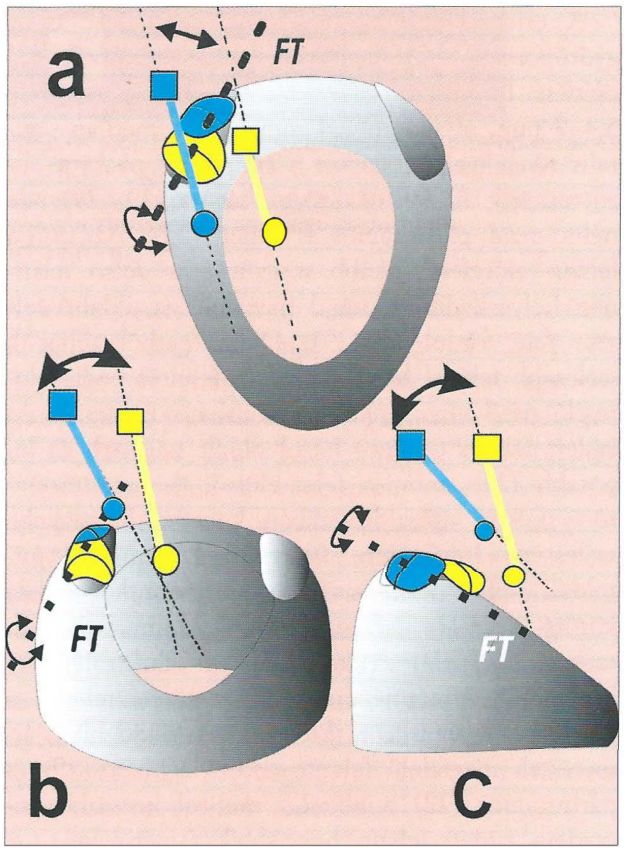
2. ábra: A cricoaytenoidalis izület gyűrűporcon lévő izületi felszíne Wang szerint.
a: oldalnézet; b: felülnézet

rőleges az izületen áthaladó tengelykörüli *rotációt* (8, 12, 13, 27); az izületi felszínen történő mediolateralis *csúszást* (4, 6); valamint az izület síkjában lévő tengelykörüli forgást, előre, vagy hátra történő *billenést* (21, 24, 28, 29).

A mozgásvetületek párhuzamossága a rotációt egyértelműen kizárja, mivel ez legalább 30°-os szöget feltételez (8, 12, 27) (*3. a ábra*). *Selbie* kinetikai modellje is alátámasztja ezt, mivel rotációnál az izület valószínűleg luxálódna (21). A mediolateralis csúszás abductiónál csak úgy jöhetne létre, ha a kannaporc a gyűrűporc hosszanti izületi tengelyén hátulról előre kerülne (*3. b ábra*). Méréseink alapján a kannaporc vetülete oldalra, de *hátrafelé* kerül, továbbá az abductiós vetület szignifikánsan hosszabb, ellentétben az ebben az esetben az eltolás matematikai törvényszerűségei alapján elvárható megközelítőleg egyenlő szakaszhosszal. Mivel a gyűrűporc anatómiai sajátosságai miatt az anterolateralis ízfelszín lejjebb helyezkedik el, mint a posteromedialis, az ebben az esetben az optikától való távolodás miatt az abductiós vetületnek is inkább kisebbnek kellene lenni. További fontos ellenvetés az elmélet ellen, hogy az izületi felszínek közti különbségek és a szalagok csak kicsi, kb. 2 mm-es elmozdulást tennének lehetővé (9, 21, 29). A *billenés* elfordulási tengelye *Sonneson* szerint a sagittalis síkhoz képest ferde, megközelítőleg megegyezik az izület hossztengelyével (24). Az utóbbi egyenest forgástengelynek tekintve (28, 29), és elvégezve a kannaporc hátra-oldalra történő „billentését", a következő eredményt kapjuk (*4. a. ábra*): a kannaporc oldalra, és hátradől, miközben a kannaporc csúcsát és a processus vocalist összekötő szakasz többé-kevésbé párhuzamos marad, bár a hátradőlés miatti nagyobb szögben történő rálátás következtében úgy tűnik, mintha némileg *meghosszabbodna* (*4. b ábra*). A processus vocalis pedig *laterálisabb* helyzetbe, és kissé *hátrébb* kerül. Ez a mintázat felel meg leginkább saját eredményeinknek. *Wang* szerint (29) ez a billenés úgy jön létre az izületben (*4. abc ábra*), hogy az adductiónál a kannaporc a cricoideus ízfelszín lateralis, elől és lejjebb lévő, de superficiális helyzetű felszínén tartózkodik. Abductiónál a feljebb lévő, medialisabb, de *kifelé forduló* hátsó felszínre kerül. Az adductiónál a folyamat fordított. Ez *Sonneson* elméletét annyiban módosítja, hogy a forgástengely, irányában és helyzetében valamelyest folyamatosan változik a mozgás során. Az izület mozgásának kinetikai modellje is ezt támasztja alá (21). Az izületi felszínek egymáson történő elmozdulása rész-



3. ábra: A jobb processus vocalis (kör), és a kannaporc (négyzet) helyzetének felülnézeti változása függőleges tengely körüli elfordulás (a), vagy medio-lateralis csúszás (b) feltételezése esetén. Az adductio sárga, az abductio kék színel jelölve.



4. ábra: A jobb kannaporc helyzete a cricoarytenoidalis izület hossztengelyére történő forgatásnál. a: felülnézet; b elölnézet:, c: oldalnézet.; a sárga jelzések adductióban , a kék jelzések abductióban mutatják a processus vocalis (kör) és a kannaporc csúcsa (négyzet) helyzetét; a kannaporc és a gyűrűporc ízfelszíneinek viszonya az abductiónál (sárga) és adductiónál (kék) Wang szerint; FT: forgástengely

ben kismértékű csúszással, részben a hossztengelyén domború alsó izületi felszín és a felső laposabb izületi felszín (9) között kialakuló, kismértékű *„gördüléssel"* magyarázható Az izület tehát leginkább egytengelyű hengerizület (gynglimus, pl. a középső ujjizületek), egy módosított változata, melyben a fix alsó ízfelszín (izületi fej) a forgástengely irányában kissé elfordult, eltolt. Ez a mozgás fiziológiai szempontból is előnyös, mert így az egész kannaporc, a processus vocalisszal együtt, belégzésnél kifelé mozdul, teljesen szabaddá téve a gyűrűporc lumenét (*4.c ábra*).

A nyitás során a processus vocalis folyamatosan sagittalis helyzetű, és kissé hátrakerül, ami a felülnézeti képet önmagában vizsgálva az oldalra csúszás, vagy rotáció illúzióját adja. Az abductió során felfelé is mozdul (*4.b ábra*), tehát kiemelkedik a *Morgagni*-tasak felé a musculus thyreoarytenoideusok síkjából. Ha ez nem történne meg, akkor a kannaporc testének lateralis felszínén és a processus vocalison tapadó izom az abductió mechanikai akadálya lenne (29). Elméletileg egyéb, összetett mozgás is létrehozhatja az általunk leírt átlagolt felülnézeti képet, (például az izületben történő előre-oldalra csúszás nagymértékű hátradőléssel kombinálva stb.), de az izületi felszínek geometriája alapján ezek olyan bonyolult izominterakciót tételeznének fel, ami gyakorlatilag kivitelezhetetlen.

Az izület mozgásának a klasszikus rotációs mechanizmustól eltérő értelmezése felvetheti, hogy mennyiben módosul ebben az esetben az egyes belső gégeizmok mozgásban elfogadott szerepe. A pajzsporc belső felszínén, az elülső szögletben eredő, a kannaporc testén lateralisan és a processus vocalison tapadó robusztus *musculus thyroarytenoideusok* összehúzódása a kannaporcot előrefelé mozdítja, és előre-befelé buktatja az alsó ízfelszínen, tehát az adductió fő izmának tartható. A *musculus interarytenoideusok* helyzetüknél fogva, a *musculus thyroarytenoideusok*kal együtt összehúzódva a hangszalagok hátsó részét közelítik az adductio során (15). Hasonlóan egyértelmű a *musculus cricoarytenoideus posterior* abductióban játszott szerepe, mivel a gyűrűporc hátsó felszínén a középvonal közelében eredő, és a processus vocalison medialisan tapadó izom, a kannaporcot a gyűrűporc ízfelszínén hátra, felfelé mozdítja, és hátrafelé billenti. Az izmok izolált ingerlése (22) is alátámasztja ezt az elképzelést. Az eddig egyértelműen záróizomként számon tartott, az előzőeknél gyengébb, a gyűrűporc oldalsó külső élén (8), és oldalsó felszínén eredő (22), és a processus vocalis lateralis oldalán tapadó *musculus cricoarytenoideus lateralis* részt vesz az adductióban, mivel izolált ingerlésével a kannaporc előre, lefelé és oldalra mozdul el. Helyzete alapján a *musculus cricoarytenoideus posterior*ral együttműködve azonban elősegítheti a kannaporc oldalra-kifelé történő billenését, és így az abductiót is (22). *Sellars* szerint, figyelembe véve a ligamentum cricoarytenoidaleval ellentétes tapadását a kannaporcon, az izom a szalag aktív antagonistájaként „kiegyensúlyozza" a két erősebb izom működését, stabilizálja az izületet.

Az „átlagos" cricoarytenoidalis izület domináló abductiós mechanizmusa tehát az oldalra, kifelé történő billenés. Az elmozdulási értékek viszonylag nagy szórása azonban jelentős egyéni eltérésre utal, sőt mozgási asszimetria gyakran egy gégén belül is észlelhető volt, bár ezt részleteiben nem vizsgáltuk. Ez valószínűleg az esetlegesen oldalanként is eltérő izületi felszínek anatómiai variációjával magyarázható (23). Felmerül azonban az a kérdés, hogy ebben az esetben az adductió rendkívül precíz, hangszalag egyeztető mechanizmusa hogy jön létre. *Sellars* (22) ezért az abductió végén egy különálló, finombeállító rotációs mechanizmust feltételez. *Wang* szerint (29) azonban ez a mechanizmus nem szükséges, mivel a hangszalagok az egyedfejlődés során adductióban, egy közös lemezből fejlődnek ki (27), így a tökéletes zárás a hangképzés során eleve adott. Az abductio szimmetriája viszont nem szükségszerű a belégzésnél. Ennek ellenére nem zárható ki, hogy az egyes izületekben kisfokú, de a *folytonos mozgás részeként jelentkező,* rotációs mozgás is létre jöhet (22).

A kannaporc, és a processus vocalis háromdimenziós rendszerben történő mozgása tehát egy jól meghatározott izületi mechanizmushoz kapcsolható. Ennek ismerete alapvető fontosságú a hangszalag helyzetét korrigáló, medializációs, vagy laterofixatiós műtéti beavatkozások kapcsán. A hosszantartó, jó eredmények biztosításához véleményünk szerint feltétlenül szükséges a kannaporc műtét alatti szabad mozgathatósága. Ezt saját tapasztalatunk szerint egy szétnyitható szárú laryngoszkóp (pl. Weerda-féle) sokkal jobban elősegíti, mint a hagyományos Kleinsasser-féle. A hátsó commissurában lévő tubus közvetlenül – laryngoszkóppal, az elülső comissurába emelt tubus a processus vocalison tapadó ligamentum vocale megfeszítésével közvetve – szintén hátrányosan befolyásolja a kannaporc mobilitását, így a megfelelő pozícióba történő elmozdítását. En-

nek kiküszöbölése érdekében a műtéteknél javasoljuk a supraglotticus JET-ventilláció alkalmazását az altató tubus helyett, a nem tracheotomizált betegeknél.

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ZUSAMMENFASSUNG: Die genaue Anatomie und Funktion des cricoarytenoidalen Gelenkes ist auch gegenwärtig eine Streitfrage. Die unterschiedlichen Größen- und Strukturverhältnisse der Gelenke, oft innerhalb eines Kehlkopfes, erschweren das Erkennen der dominierenden Bewegungsform bei den sich zumeist auf anatomische Einzelheiten konzentrierenden, wenigen Untersuchungen. Die Entwicklung der Kehlkopfchirurgie gibt der bisher fast nur als theoretisches Problem diskutierten Frage gezielte, praktische Bedeutung. Verff. untersuchten in 100 Kehlköpfen die Bewegung der Aryknorpel in der Sicht von oben mit der Bild-digitalisierenden Technik und mittelten die Werte der Flächenverschiebung. Die so erhaltenen Bewegungsmuster verglichen sie mit den zu erwartenden Bewegungsmustern der drei vermutlich häufigsten Bewegungsformen: der Rotation (vertikale Drehung um die Achse), der seitlichen Verschiebung bzw. dem Kippen (Drehen um die horizontale Achse des Gelenkes). Aufgrund der Ergebnisse dominiert die letztere bei den Bewegungen des Kehlkopfes, was auch mit den neuesten anatomischen Untersuchungen übereinstimmt. Die dreidimensionale Bewegung von Aryknorpel und Processus vocalis kann mit einem bestimmten Gelenkmechanismus in Verbindung gebracht werden, dessen Erkenntnis langdauernde und gute Ergebnisse für die stimmbandkorrigierenden Operationen (Medialisierung oder Laterofixation) ermöglicht.

SCHLÜSSELWÖRTER: Bild-Digitalisierungstechnik, chirurgische Stimmritzenerweiterung, cricoarytenoidales Gelenk, Stimmbandbewegung, Stimmband-Medialisierung

IX.

MORPHOMETRIC ANALYSIS OF HUMAN LARYNGEAL IMAGES FOR OPTIMALISATION OF SUTURE LATERALIZATION INSTRUMENTS

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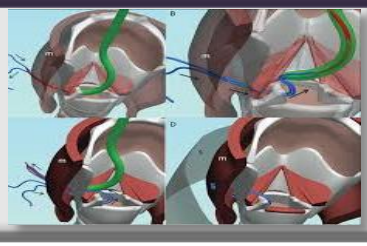
Introduction

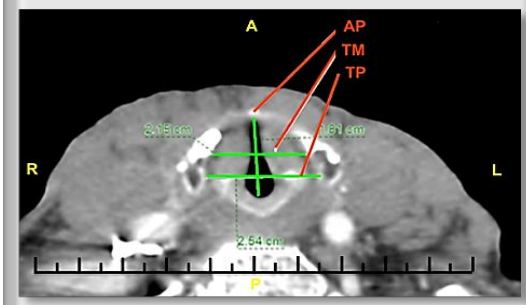
Bilateral vocal cord immobility (BVCI) due to vocal cord paralysis is a life threatening condition, that can be managed in numerous way. Although most of these methods help to avoid tracheotomy, anatomical destruction of the vocal fold and irreversibility remain a problem. Moreover, unfavorable effect of these methods on voice quality, aspiration, and consequent lower airway complications leads to deterioration of patients' quality of life. To maximize airway restoration in BVCI with minimal long term side effect, an Endolaryngeal Thread Guide Instrument (ETGI) was developed in our department. With this equipment, Endoscopic Arytenoid Abduction Lateropexy (EAAL) is performed, which provides a wide-open glottis by allowing the vocal cords to be kept in an abducted position with a double loop suture. The method is reversible and does not result in anatomical destruction. Therefore there is a possibility of the vocal cords to have motion due to residual innervation or re-innervation.



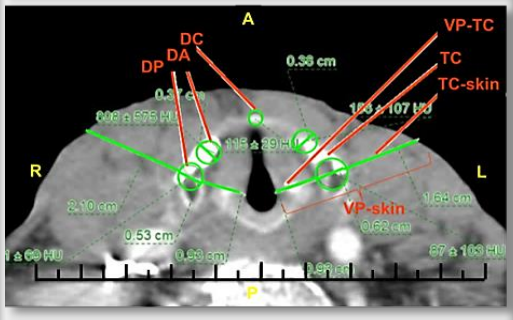
Patients and methods

The aim of the study was to define the ideal size of ETGI blade; to avoid spatial limitation of the method due to disproportion between instrument and laryngeal spaces, ETGI blade size was designed after having evaluated cervical CT scans [n=56 male, n=41 female, Caucasian participants, 51±18 year, (50±17 year in male group, 54±20 in female group] with Picture Archiving and Communication System (PACS). Our measurements aimed to assess glottal space, endolaryngeal distances between different anatomical structures and surfaces, density of the thyroid cartilage [Hounsfield units (HU)] and compressibility of soft tissue at the level of the thyroid cartilage. Statistical analysis was performed with SigmaStat 4.0 statistical software (Systat Software Inc, California). Data are expressed in mean ± SD.

Radiological measurements



Picture 1: Representative image from our study. Different parameters determine the glottic size:
- **AP**: Antero – posterior length in the midline
- **TM:** Transverse length at the midpoint of the glottis
- **TP:** Transverse posterior is a length at the level of the vocal process of the arytenoid cartilage



Picture 2: Representative image from our study. All measurements were made in both sides right and left at symmetrical points and the density was measured in HU.
Specific laryngeal distances:
- **VP-TC**: vocal process -internal lamina of thyroid cartilage
- **TC**: thyroid cartilage-inter lamina of thyroid cartilage
- **TC-Skin:** external lamina of thyroid cartilage-surface of the skin
- **VP-Skin**: vocal process -surface of the skin

Density measurement of the thyroid cartilage:
- **DC**: density-central: density at the level of anterior angle
- **DA**: density-anterior: density at the anterior one third of the lamina
- **DC:** density-posterior: density at the level of vocal process.

Results

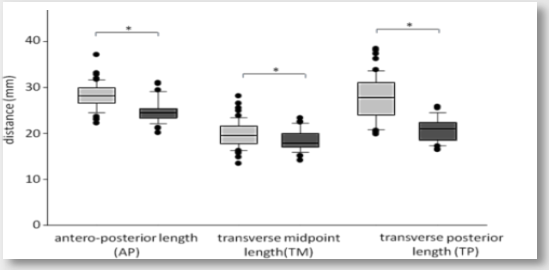
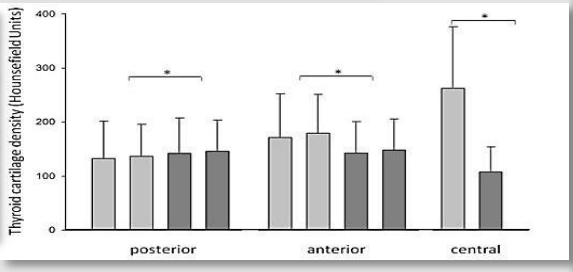


Figure 1:Parameters of the glottic opening: AP-anteroposterior, TM-transverse midpoint and TP-transverse posterior length. Data is expressed in mm. Light grey boxes represents male, dark boxes represents female group. * Level of significance: p=0.001

Figure 2.: Density of the thyroid cartilage (central-DC, anterior-DA and posterior-DP) Light grey boxes stand for male, dark boxes stand for female group, left and right sides. *Level of significance: p=0.001



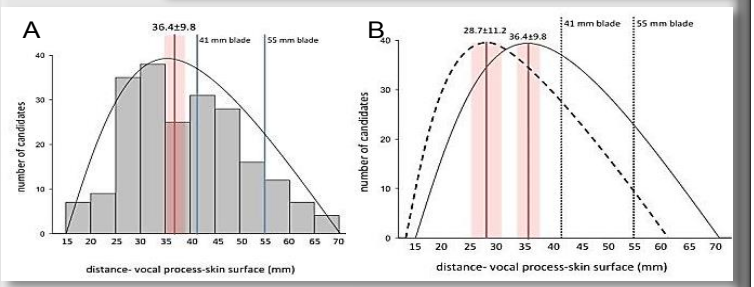


Figure 3.: 3A: Distribution (grey boxes and black curve) of tissue thickness i.e. distance between the surface mucosa of the vocal process to skin surface. Average thickness is shown with red line (mean) and box (standard deviation i.e. SD). **3B** Distribution of tissue thickness i.e. distance between the surface mucosa of vocal process to skin surface with and without soft tissue compression. Full lined curve indicates thickness distribution without compression of surface soft tissue. External compression of surface soft tissue shifts the distribution to the left and reduces average tissue thickness, marked with red line and box (mean ±SD). Based on the results, length of the ETGI blades determined (41 mm and 55 mm) shown with blue line on picture A and dotted line on picture B. With tissue compression, 90% of the cases can be solved with a 41 mm and 99% with a 55 mm blade (without compression this ratio is 69% with 41mm and 94%).

Conclusion

- male glottis proved to be significantly larger than the female glottis
- although the blade trajectory from the vocal process to the skin was equal in both genders, the distance between the vocal processes to the internal lamina of TC was longer in males (non-compressible), while neck soft tissue (compressible) was significantly thicker in females
- on the basis of our measurements, two blade sizes were developed: a 41 mm in length for female patients with higher compressibility and a 55 mm in length for male patients. Without tissue compression, 69% of all cases can be treated with the 41 mm and 90% with the 55 mm blade. With compression, this ratio is 90% and 99%, respectively

A new thread guide instrument for endoscopic arytenoid lateropexy. (Rovó et. al. 2010 Laryngoscope)
Comparison of endoscopic techniques designed for posterior glottic stenosis--a cadaver morphometric study. (Sztanó et. al. 2014. Larynoscope)
A comparison between transoral glottis-widening techniques for bilateral vocal fold immobility. (Szakács et. al. 2015)