# NEW ASPECTS OF CLINICAL APPLICATION OF ENDOSCOPIC ARYTENOID ABDUCTION LATEROPEXY

**PhD Thesis**

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**Szeged**
**2018**

# PUBLICATIONS RELATED TO THE PhD THESIS

I. **Bach Á**, Sztanó B, Kiss JG, Volk GF, Müller A, Pototschnig C, Rovó L.
**The role of laryngeal electromyography in the diagnosis of vocal cord movement disorders.** [A laryngealis electromyographia szerepe a hangszalag-mozgászavarok diagnosztikájában és az alkalmazott kezelés kiválasztásában] Orv Hetil. 2018;159:303–311.
Impact factor: 0,349

II. **Bach Á,** Sztanó B, Matievics V, Bere Z, Volk GF, Müller A, Förster G, Castellanos PF, Rovó L.
**Isolated Recovery of Adductor Muscle Function Following Bilateral Recurrent Laryngeal Nerve Injuries.** Accepted for publication in The Laryngoscope on 05 November, 2018, DOI: 10.1002/lary.27718
Impact factor: 2,442

III. Rovó L, **Bach Á**, Sztanó B, Matievics V, Szegesdi I, Castellanos PF.
**Rotational thyrotracheopexy after cricoidectomy for low-grade laryngeal chrondrosarcoma.** Laryngoscope. 2017;127:1109-1115.
Impact factor**:** 2,442

# CITABLE ABSTRACTS

I. Rovó L, **Bach Á**, Matievics V, Szegesdi I, Castellanos PF, Sztanó B.
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**Adductor reinnervation after recurrent laryngeal nerve injuries – Its clinical importance in bilateral vocal cord paresis**.
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IV. **Bach Á**, Sztanó B, Szakács L, Rovó L.
**Function preserving solution of a chondrosarcoma of the cricoid cartilage.** (PP80)
10th Congress of the European Laryngological Society, April 9-12, 2014, Antalya, Turkey

V. **Bach Á**, Sztanó B, Matievics V, Szakács L, Rovó L.
**Life quality before and after a reversible glottis enlarging procedure.** (PP82)
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VI. Sztanó B, Szakács L, Madani S, **Bach Á**, Bere Z, Rovó L.
**Endoscopic arytenoid abduction lateropexy for the treatment of bilateral vocal cord immobility – pediatric application**
2nd Congress of CE-ORL-HNS, April 27-30, 2013, Nice, France

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I. Matievics V, Sztanó B, **Bach Á**, Rovó L.
**Phoniatric outcomes of endoscopic arytenoid abduction lateropexy in patients with transient bilateral vocal cord paralysis.** [Endoszkópos arytenoid abdukciós lateropexia foniátriai eredményei átmeneti kétoldali gégebénulás esetén] Orv Hetil. 2018;159:1188-1192.

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**A new solution for neonatal bilateral vocal cord paralysis: Endoscopic arytenoid abduction lateropexy.** Laryngoscope. 2017;127:1608-1614.

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# ABBREVIATIONS

**BVFI** Bilateral Vocal Fold Immobility

**BVFP** Bilateral Vocal Fold Paralysis

**CRD** Complex Repetitive Discharge

**EAAL** Endoscopic Arytenoid Abduction Lateropexy

**EMG** Electromyography

**ETGI** Endolaryngeal Thread Guide Instrument

**$F_0$** Fundamental frequency

**HNR** Harmonics to Noise Ratio

**LEMG** Laryngeal Electromyography

**MUAP** Motor Unit Action Potential

**PCA** Posterior Cricoarytenoid Muscle

**PIF** Peak Inspiratory Flow

**PSA** Pathological Spontaneous Activity

**QOL** Quality of Life

**SWAL-QOL** Swallowing Quality of Life

**TA** Thyroarytenoid Muscle

**UDP** Ultra Dream Pulse

# CONTENT

# 1. INTRODUCTION

The adequate treatment of bilateral vocal fold immobility (BVFI) is still one of the biggest challenges of Laryngology due to the sophisticated balance between improving breathing and limiting deterioration of voice and swallow function [1]. Bilateral vocal fold paralysis (BVFP) is the most common form of the BVFI syndrome, caused by injury to both recurrent laryngeal nerves. The leading causes include surgery (predominantly thyroid), intubation, trauma, neurological disorders and extralaryngeal malignancies [2-5]. The classical presentation of patients with BVFP is inability to abduct the vocal folds with the resulting narrow glottic chink, compromised airway, inspiratory stridor, and slightly influenced voicing. Such patients are in a precarious position with respect to the airway. Depending on the width of the remaining glottic chink, their body mass, the presence of comorbidity and their usual physical activity, the patients may have dyspnea of a varying degree and respective complaints [6,7]. Most of these patients must undergo some kind of surgery for enlargement of the airway. For centuries tracheotomy has been the golden standard for securing it. Numerous surgical techniques for glottis enlargement have been introduced during the past decades. These interventions could be classified according to the morphologic changes they cause at the glottic level, and according to the surgical exploration [8]. The current trends from the eve of the twentieth century are towards endoscopic minimally invasive techniques.

The endoscopic arytenoid abduction lateropexy (EAAL) was introduced by the upper airway stenosis workgroup of the Department of Oto-Rhino-Laryngology, Head and Neck Surgery, University of Szeged as a novel treatment option for vocal fold impairment [9]. The procedure is based on the lateralization of the arytenoid cartilage with the membranous vocal fold. The entire vocal unit is displaced in a physiological manner without resection of phonatory structures. The intervention is a quick, non-destructive, reversible, minimally invasive technique which immediately provides a stable, wide glottic airway in bilateral vocal fold paralysis [10-13]. EAAL does not harm neither the passive (cartilaginous) nor the active (neuromuscular) structures of vocal folds. Thus, due to its unique non-invasive manner it allows the investigation of the potential regeneration of the vocal fold movements in BVFP patients if reinnervation occurs. Moreover, theoretically in case of adduction recovery it gives a place of an active dynamic phonation to improve the vocalization of the patient. Better understanding of the neural regeneration process might lead to the more favorable dynamic rehabilitation of vocal fold immobility.

Electromyographic (EMG) investigations of the laryngeal muscles are indispensable for this purpose. Although recognized as a valuable diagnostic tool for more than 70 years, many laryngologists do not routinely use laryngeal electromyography (LEMG). This may be due to a persisting lack of agreement on methodology, interpretation, validity, and clinical application of LEMG [14-17]. To achieve consensus in these fields, a laryngeal electromyography working group of European neurolaryngologic experts was formed in 2012 in order to evaluate guidelines for LEMG performance and identify issues requiring further clarification [18]. Our research team joined this international LEMG group in 2013 to reintroduce this diagnostic tool in Hungary [19,20]. Our team performed LEMG in more than 100 patients since then.

EAAL was originally invented for the treatment of vocal fold paralysis, but it is also a useful method in the endoscopic treatment of posterior glottic stenosis to separate the arytenoid cartilages during reepithelization after laser resection of the interarytenoid scar tissue [21-23]. Adducted position of the vocal fold(s) or intraluminal collapse of the (supra)glottic soft tissues may occur in other special pathological situations as well. In cases of partial or total cricoidectomy due to malignant lesions, the inability to reconstruct the laryngeal structures often leads to permanent tracheostomy or even total laryngectomy [24-26]. EAAL might be an alternative solution in these cases, in which the stability of the arytenoid cartilages is impaired due to the damage of the cartilaginous framework of the larynx.

I have been working in the Department of Oto-Rhino-Laryngology, Head and Neck Surgery, University of Szeged since 2011. In the first year of my residency I have joined to the upper airway stenosis workgroup under the supervision of Professor László Rovó. Over the past 7 years I took part in several operations of different types of airway stenoses in adult and pediatric patients as well. In 2013 I became the member of the international laryngeal electromyography team and I've participated several neurolaryngology workshops in Germany.

During my daily work, one of my main tasks is to perform the preoperative and postoperative laryngeal functional examinations for measuring the airway improvement and voice quality changes of BVFI patients. Related to this, my other important task is to perform the neurolaryngological examinations and follow-up the patients to register the potential regeneration of the vocal fold movements.

## 2. ENDOSCOPIC ARYTENOID ABDUCTION LATEROPEXY – BACKGROUND AND SURGICAL TECHNIQUE

In the clinical practice, suturing of the vocal fold laterally (laterofixation) as a sole intervention procedure for glottis enlargement without any tissue resection was first used by Ejnell [27]. He introduced a thread through the thyroid lamina using two injection needles. The major problem with this technique was the difficult orientation of the needles resulting often in multiple and wide stitching canals, which present a potential risk factor for infection. An important step further was the introduction of the endo-extralaryngeal approach by Lichtenberger, based on a specially constructed needle-carrier [28,29]. As the atraumatic needles are introduced endoscopically from inside to outside of the larynx, the placement of the threads was done in an extremely precise way. However, the simple rotation around the vertical axis, which is generally considered to be the theoretical basis for simple vocal fold laterofixation techniques, does not allow the maximal possible abduction for the arytenoid cartilages.

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, 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 [30]. To achieve this physiological displacement passively, more posterior fixating loop(s) must be inserted. These posterior sutures are practically impossible to be inserted through an externally inserted needle or by the original Lichtenberger device because the thyroid cartilage is denser in that area. For this reason, endoscopic arytenoid abduction lateropexy (EAAL) and a new endolaryngeal thread guide instrument (ETGI) was introduced [31] (Figure 1,2.). With this special instrument, this simple, quick and safe procedure enables the endoscopic creation of two fixating loops in one step at suitable laryngeal locations, providing maximal physiological abduction of the arytenoid cartilage.

In a previous study EAAL was compared to other popular glottis enlarging techniques. EAAL proved its efficacy: it provided the largest glottic space and the postoperative glottis configuration was beneficial to preserve the patients' voice quality [32,33]. The functional result regarding the breathing were also convincing in patients with excessive posterior glottic stenosis [21-23]. The purpose of our method is to provide the largest possible space in the posterior commissure via (bilateral) EAAL thus keeping the wounds apart until healing, 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 [34].

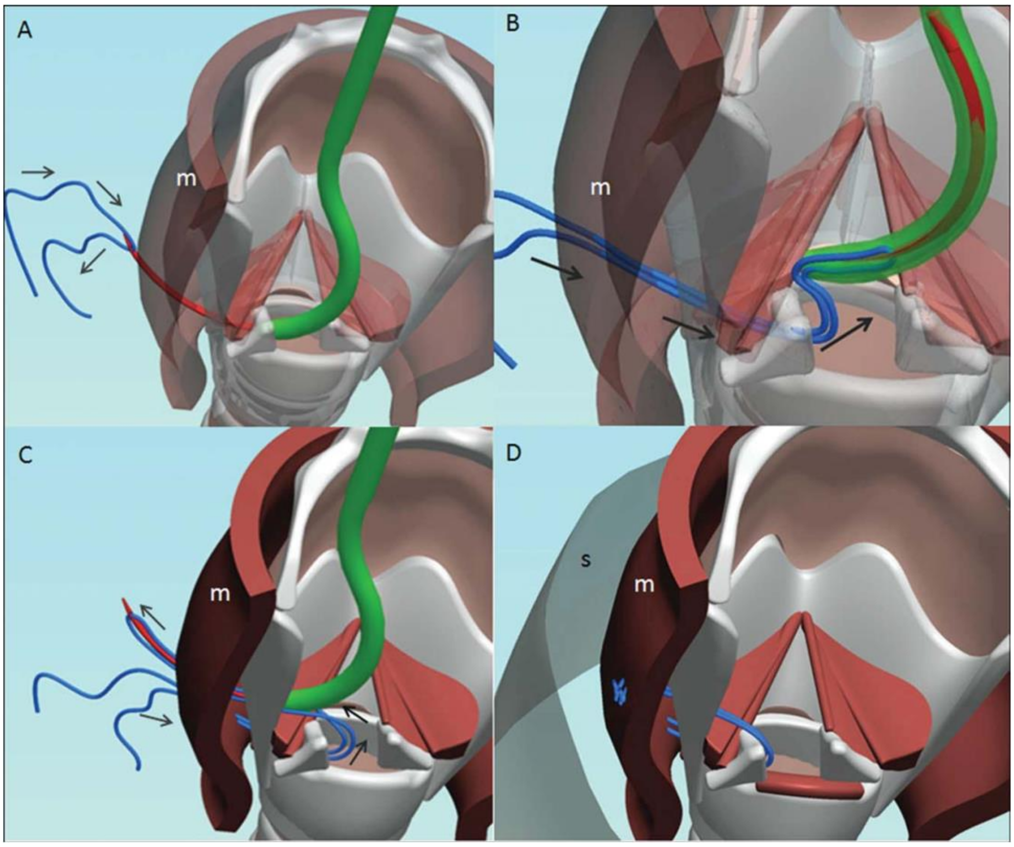


**Figure 1. Schematic drawing of the endoscopic arytenoid abduction lateropexy (EAAL).**
The skin (s) is illustrated only on the last picture to achieve better visualization. Arrows indicate the direction of the thread guiding. m= sternohyoid muscle.

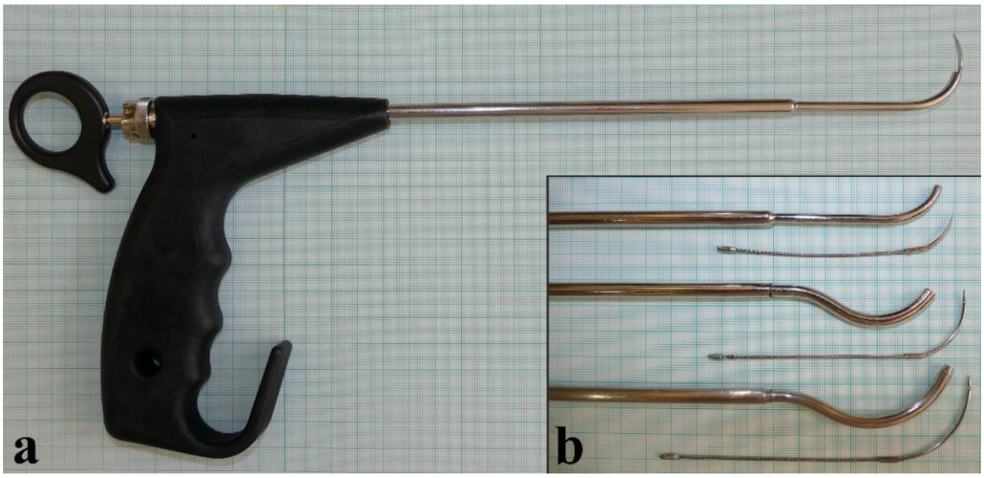


**Figure 2. Endolaryngeal Thread Guide Instrument (ETGI).**

a) Handling, stem-pipe and curved blade in pushed-out position (stem-pipe and blade designed for infants
b) Blades and stem-pipes designed for infants, females and males (from top to bottom)

# 3. AIMS OF THE THESIS

1. Introducing laryngeal electromyography in the clinical routine for the complex evaluation of BVFI patients and standardize this diagnostic method.
2. Electrophysiologic examination of neural regeneration of the inferior laryngeal nerve in BVFP patients treated by EAAL.
3. Examination of the effects of spontaneous, isolated recovery of adductor muscle function on voice quality, breathing function and life quality in BVFP patients treated by unilateral EAAL.
4. Introducing EAAL for the complex reconstruction of the glottic and supraglottic airway after partial and total cricoidectomy.

# 4. INTRODUCTION OF LARYNGEAL ELECTROMYOGRAPHY INTO CLINICAL PRACTICE

## 4.1. Introduction

The differential diagnosis of vocal fold motion disorders is dominantly based on the endoscopic findings with or without the additional help of laryngo-stroboscopy. With enough experience these subjective methods allow the differentiation of vocal fold motion impairment with mechanical or neurogenic origin and make other neuromuscular diseases (e.g. spastic dysphonia, myasthenia gravis) recognizable as well. However, in cases of paresis or paralysis of vocal fold muscles, they do not provide an opportunity to determine the grade of neural injury or the prognosis of the disease. Nevertheless, in case of vocal fold paralysis these factors fundamentally determine the indication and type of the potential glottis widening intervention.

Due to the rapid development of laryngeal surgical techniques, an objective diagnostic method has become increasingly important in recent decades to answer the above-mentioned problems. An appropriate solution is the laryngological application of electromyography, which has been used in the diagnostics of neuromuscular diseases for decades [14-19]. The application of this tool is highly important in the clinical practice, thus potential glottic surgery, which is based on the electrophysiological results, fundamentally determines the patient's quality of life. As a member of the upper airway stenosis workgroup, I attended special laryngeal electromyography workshops three times in 2013 and 2015 in Jena, Hamburg and Würzburg as well. After the animal and cadaver experiments, we started our human trial in 2014 (Figure 3.).

**Figure 3. Transcutaneous electric stimulation of the laryngeal muscles under endoscopic visualization in pig model. (2014, Jena, Germany)**

## 4.2. Method

### 4.2.1. Indications, contraindications

Vocal fold motion impairment is a clinically heterogeneous disorder that provides challenges in diagnosis and management at every level. The abnormal innervation of laryngeal muscles, cricoarytenoid joint dislocation or ankylosis, glottic scarring or glottic fixation by malignant lesion all lead to a similar symptom complex [35]. The main goal of laryngeal electromyography is the differentiation of vocal fold immobility with mechanical and neurological origin. In case of neurological origin LEMG helps to determine the grade of neural injury and might predict the chance of reinnervation and motion recovery. In connection with different augmentation and injection techniques, LEMG is also helpful for the identification of the exact place for the injection (e.g. botulinum toxin, hyaluronic acid) [36-39].

Electromyography of skeletal muscles has practically no absolute contraindication [40]. However, due to the unique state of the larynx special attention must be paid during LEMG. In case of compromised airway LEMG must not be performed! Due to the extremely uncommon, but potentially fatal complications (especially in BVFI) one must be ready for intubation, or conicotomy. Coagulation disorders, local skin lesions, edema are relative contraindications, such as a cardiac pacemaker during electric stimulation. Bloodborne diseases (e.g. HIV, Hepatitis) can be prevented with adequate sterility. We performed LEMG only in adult patients so far, but general anesthesia without muscle relaxation makes the technique feasible in pediatric patients as well [41].

### 4.2.2. Equipment

*Electromyography electrodes:* During electromyography, the summed outcomes of the muscular fiber's potentials are recorded with an extracellular electrode. This summation potential is called motor unit potential. For its registration surface and indwelling (needle) electrodes are used. For diagnostic purposes, usually transcutaneous EMG is performed. Accordingly, concentric needle electrode is appropriate. 50 mm long needle electrode allows the translaryngeal reach of the posterior cricoarytenoid muscle (PCA) through the cricoid plate as well. However, this requires a rigid electrode with a diameter of at least 0.45 mm. In order to the comparability and repeatability, same type of needles must be used in every patient. (TECA Elite, Disposable Concentric Needle Electrode, 37 mm × 26 G; 50 mm × 26 G; Natus Neurology Inc., Middleton, WI, USA).

*Microphone:* When a microphone is connected to the channel of a multichannel EMG amplifier, a synchronic voice recording is possible. This allows a comparison of myoelectric activity with the patient's sound production. Additionally, the recorded instructions and comments of the examiners can be helpful for the interpretation of the stored data.

*Thermistor and piezoelectric thorax expansion belt:* Respiration is another fundamental parameter of voice production. It can be measured by placing a thermistor in front of a patient's nose, mouth or tracheostomy. A thermistor detects the changes of air temperature caused by every breath and can thus be used to record respiration activity. Alternatively, the movement of the chest wall and/or the upper abdominal wall can be monitored by using thorax and/or abdomen expansion belts with piezoelectric sensors. This movement is related to effort and produces a low frequency sinusoidal waveform as the patient inhales and exhales.

*Indirect laryngoscopy:* Transnasal flexible fiberoscopy gives additional information and makes easier to evaluate the relationship between the electric signals and the actual vocal fold movements.

*EMG amplifier:* Neuropack X1 (Nihon Kohden Corp., Tokyo, Japan) EMG amplifier was used for our examinations. This device can record up to 12 channels and makes the electric stimulation of the laryngeal muscles also possible. The raw data was processed with a special EMG analyzing software, which was encoded by MATLAB (The MathWorks Inc., Natick, MA, USA) [42]. The EMG signals were evaluated with Audacity 2.1.3 software (http://audacityteam.org).

### 4.2.3. EMG monitoring

Laryngeal electromyography is a medical procedure requiring active cooperation by the patient. Thus, appropriate information and written consent of the patient cannot be ignored. The patient's ability and willingness to cooperate must be considered when planning an LEMG examination. In addition, a detailed examination of the head and neck, including indirect or fiberoptic laryngoscopy and/or videostroboscopy, is important to detect altered anatomy, previous operations, or acute infections - conditions which can potentially hinder the placement of the electrode. In our protocol the voice recording, and spirometry always precedes the LEMG examination. Spontaneous fibrillation activity indicating axonal degeneration does not appear until 10 to 14 days after the initial injury, which means that LEMG performed before that time may not be fully reflective of the extent of injury [14].

For LEMG, the patient is asked to adopt a comfortable position with a slightly reclined head (Figure 4.a,b). If necessary, the larynx can be anaesthetized locally with lidocaine, either applied transorally to the mucosal surface or with a transcutaneous intraluminal injection. After the disinfection of the skin and positioning of the above-mentioned sensors, the examination is about to begin.


**Figure 4. Implementation of laryngeal electromyography.**

a) Examination of the posterior cricoarytenoid muscle
b) Examination of the left thyroarytenoid muscle

e = electrode; m = microphone; me = piezoelectric thorax expansion belt; t = thermistor

At the beginning of the examination, main structures of the anterior neck are palpated to identify the midline, the cricoid cartilage, the lower border of the thyroid cartilage and the thyroid notch. It is recommended to begin the LEMG with the thyroarytenoid muscle (TA), followed by an examination of the posterior cricoarytenoid muscle (PCA). The cricothyroid membrane is the most important anatomic reference for the needle insertion. First, the needle pierces the skin in midline in sagittal direction and will be placed directly under the lower border of the thyroid cartilage. Second, the needle tip will be angled laterally and superiorly and penetrates through the cricothyroid ligament without entering the airway. Depending on the thickness of the neck and the entry angle, the thyroarytenoid muscle should be reached after pushing the needle 15 mm through the ligament (Figure 4.b; 5.a,b). Coughing of the patient generally indicates that the needle has penetrated the airway and is causing irritation of the mucosa. A burst of sine waves modulated by phonation also indicates that the electrode tip has entered the airway. The position of the needle is confirmed by asking the patient to say /i:/. During this, EMG activity sharply increases. Furthermore, swallowing causes a short strong thyroarytenoid activity during the glottal stop. While deeply breathing in and out, the resting activity drops periodically during expiration.

Posterior cricoarytenoid muscle usually accessed by passing a needle posteriorly through the cricothyroid membrane, airway, and cricoid cartilage. For this midline approach, again, the cricothyroid notch is the anatomic reference for the needle insertion. The needle pierces the skin and penetrates the cricothyroid ligament in the midline in a sagittal direction. A burst of sine waves modulated by phonation indicates that the electrode tip is vibrating freely in the airway. After entering the airway, irritation of the mucosa may cause the patient to cough. Approximately 5–10 mm lateral to the midline the posterior mucosa of the airway is penetrated. By slowly rotating the needle, it is drilled through the lamina of the cricoid cartilage. Having penetrated the whole cartilage, the tip of the needle should be right in the PCA muscle (Figure 4.a, 5.c,d). Pushing any further will cause a penetration of the cricopharyngeal muscle. The correct position is confirmed by detecting increased EMG activity during sniffing, and considerably weaker EMG activity during swallowing and phonation of the sound /i:/. If the needle is placed too deeply, recording the activity of the cricopharyngeal muscle, a strong constant EMG activity will be observable, decreasing during swallowing.

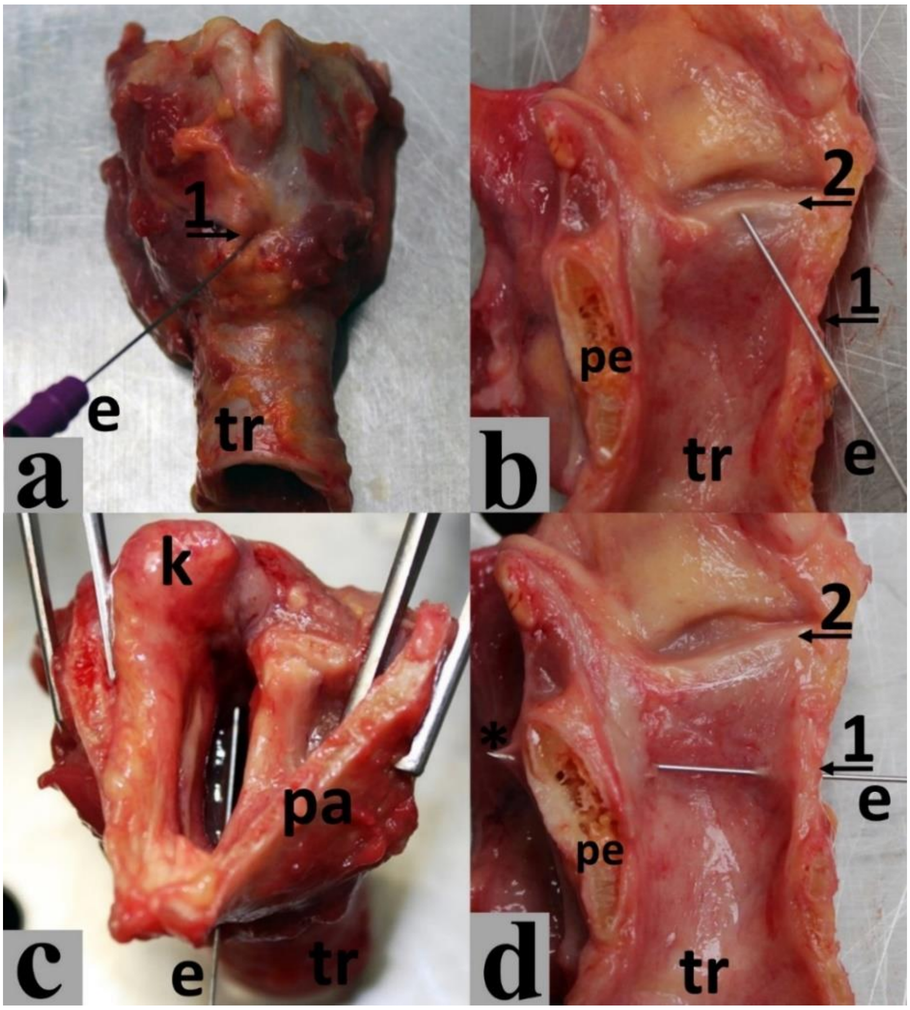


**Figure 5. Position of the LEMG electrode during the examination of the left thyroarytenoid muscle (a, b) and left posterior cricoarytenoid muscle (c, d); cadaver larynx**

a) The electrode penetrates the cricothyroid ligament (anterior view)
b) The tip of the electrode is placed in the left vocal fold. Due to the illustration, the needle is not placed under the mucosa. (inside view)
c) The electrode penetrates the lamina of the cricoid cartilage through the cricothyroid ligament and the intralaryngeal space. (plan view)
d) The electrode reaches the posterior cricothyroid muscle after the penetration of the cricoid lamina. Due to the illustration, the tip of the needle (*) penetrates the muscle more than necessary. (inside view)

1 = cricothyroid ligament; 2 = left vocal fold; e = LEMG electrode; k = right arytenoid cartilage; pa = thyroid cartilage; pe = cricoid lamina; tr = trachea

To reveal the complex electric activity of the laryngeal muscles the patient is asked to perform agonistic and antagonistic maneuvers while recording LEMG. The electric activity is analyzed during phonation, forced sniffing inspiration and during calm ex- and inspiration for 30 sec. For the differential diagnoses of recurrent laryngeal nerve paralysis and other causes of vocal fold immobility, temporary electrical stimulation of the PCA could be performed. This method is applied only for experimental purposes in general anesthesia.

**4.2.4. Interpretation of LEMG**

An EMG examination should be performed and evaluated in a structured and standardized way. In a widely used scheme, the EMG of skeletal muscles is evaluated during insertion, at rest, and during different strength of volitional contraction. These standards cannot be simply transferred to laryngeal EMG, because the volitional activation of an individual laryngeal muscle is not possible. When activated, the laryngeal muscles perform complex movements always involving multiple muscles [18]. In case of vocal fold immobility complex and personalized examination is necessary. None of the diagnostic methods is conclusive alone.

During EMG, the morphology (shape, amplitude, duration) of the motor unit potentials is analyzed. Unlike the skeletal muscle, a nerve fiber innervates only smaller muscle groups in the larynx. Thus, motor unit potentials are shorter and have smaller amplitude compared to the skeletal ones. The amplitude shows the number and strength of the muscular fibers innervated by an actual nerve. The length of the electrical signal depends on the speed of nerve conduction, which is mostly influenced by the "isolation" of the nerve fiber. The power of muscle contraction is determined by the number of operating motor units and their discharge frequency. Parallel to the activated motor units and their discharge frequency, the muscle strength increases. Motor unit recruitment refers to the activation of additional motor units to accomplish an increase in contractile strength in a muscle. Accordingly, the density of the registered interference pattern correlates to the number of activated motor units and muscle force. Neural and muscular injuries lead to a decrease in the number of motor unit potentials and recruitment during the volitional activity of the muscles [18].

During the insertion of the needle into the muscle, an insertion activity should occur. Typically, the insertion of the needle causes bursts of electrical activity. These should last no longer than several hundred milliseconds. They are caused by the fact that the needle itself contains some electrical energy, which, when placed near the muscle membrane, causes a relative change in the surrounding electrical field. If the electrical charges surrounding the muscle membrane are unstable, e.g., during early nerve and muscle injuries, the insertional activity is prolonged. Healing of nerve and muscle injuries sometimes results in the replacement of normal muscle with scar tissue or fat, which insulates the remaining muscle fibers and causes a decrease in insertion activity.

In contrast to skeletal muscles, in which electric silence can be observed during relaxation of the target muscle, it is hardly possible for a healthy and awake person to reach complete relaxation of the larynx. The optimal resting condition of the small laryngeal muscles can be observed during quiet breathing. The physiological background activity makes it hard to interpret muscle activity triggered by inserting the needle. Equally, detecting pathological spontaneous activity is much more difficult in laryngeal than in most other muscles. At the same time, a lesion of the nerve also reduces the background activity and thus often makes the interpretation easier than in physiologically innervated laryngeal muscles.

In a resting muscle with a non-moving electrode, the examiner should check for pathological spontaneous activity. Spontaneous activity can include fibrillation potentials, increased insertional fibrillations (insertional activity), myotonic discharges, complex repetitive discharges, fasciculations, and positive sharp waves. The most typical pathological spontaneous activities are the fibrillation potentials. These are defined as low-amplitude, short-duration units generated by a single-muscle fiber indicating axonal degeneration. This symptom may occur only 10–14 days after the injury. This degree of denervation occurs only in severe nerve injury. Spontaneous activity indicates a poor prognosis for recovery. During total denervation, the muscle has no neural input, thus abnormal EMG activity cannot be registered. Once regeneration begins, the muscle receives electrical impulses from the regenerated nerve and the spontaneous activity ceases.

For routine clinical use, it is convenient to classify electrophysiological findings according to Seddon into neurapraxia, axonotmesis, or neurotmesis [43]. For neurapraxia, the diagnostic criterion in LEMG is the detection of a rarified recruitment pattern or single action potentials during volitional contraction without pathological spontaneous activity (e.g., positive sharp waves or fibrillation activity). Neurapraxia is most likely to recover completely within 8–12 weeks. The number of polyphasic potentials and the amplitude of motor unit potentials increase during regeneration, while the number of the fibrillation potentials decrease. Axonotmesis should be suspected if spontaneous activity, indicating neural degeneration, is detected. Axonotmesis is thought to have only a poor chance of recovery to a functional level. If reinnervation occurs following axonotmesis, it is usually associated with sequelae, such as synkinesis, due to neuronal misdirection [44-48]. Neurotmesis, i.e., the complete destruction of the whole nerve structure across its entire diameter, is assumed never to recover unless the damaged nerve endings have direct contact.

# 5. ISOLATED RECOVERY OF ADDUCTOR MUSCLE FUNCTION FOLLOWING BILATERAL RECURRENT LARYNGEAL NERVE INJURIES

## 5.1. Introduction

The treatment of bilateral vocal fold immobility is still one of the biggest challenges in Laryngology. This has been attributed the "zero-sum" balance between the need to improve breathing at the expense of sacrificed voice and swallowing functions [1]. While no debate exists about that the need for an immediate and stable airway is paramount, it is possible to achieve this while sustaining a satisfactory voice and protection from aspiration by using a minimally invasive, non-destructive and reversible glottis widening surgical technique [8]. This way the "zero-sum" game can become a "win-win".

Theories have changed fundamentally since the Semon-Rosenbach and Wagner-Grossman hypotheses about the reason of the typical paramedian position of the vocal fold(s) after recurrent laryngeal nerve injury [49-51]. Animal studies clearly demonstrate, that the recurrent laryngeal nerve has a very strong potential to regenerate after injury. It has also become evident that most patients with recurrent laryngeal nerve injury attain varying levels of spontaneous recovery [52-56]. Partial or even total recovery of vocal fold movement can be seen in untreated patients with unilateral or even bilateral vocal fold palsy. Currently, the widely accepted conventional "static" glottis widening techniques are based on the partial or complete resection of the arytenoid cartilage and/or the vocal fold. Clinical signs of recovery, which are commonly in the form of vocal fold adduction, are not easily detected in patients who are treated with glottis and/or arytenoid resection procedures, although laryngeal electromyography (LEMG) can demonstrate some degree of reinnervation [50, 52]. Thus, despite the neural regeneration, vocal fold movement may not be *physically possible* or may be undetectable and ineffective because of the surgery performed. Moreover, after transverse cordotomy due to scarring the paralyzed arytenoid remains in the adducted position.

By contrast, the non-destructive, minimally invasive glottis widening technique, the endoscopic arytenoid abduction lateropexy (EAAL), does not damage either the surgically treated or the contralateral vocal fold, and, therefore can take advantage of the regeneration of the recurrent laryngeal nerve [10,11,31,32,33,57]. This way, the devastating clinical and physiological conundrum resulting from BVFP is reversed: instead of being closed, the glottis is surgically opened; but it is able to close during phonation or swallowing processes. A thorough analysis of LEMG, spirometric and acoustic tests are required to assess the comparative advantage of this surgical method compared to conventional interventions performed for BVFP.

### 5.2. Materials and methods

#### 5.2.1. Patients

Twenty-one consecutive patients were diagnosed and treated with unilateral EAAL because of BVFP caused by thyroid surgery. Ten of the 21 (48%) patients (9 females and 1 male, mean age 54.9 years, range 34-75 years) showed endoscopic signs of only adduction recovery during the follow-up 1-year period; this homogenous group of patients with adduction only recovery without any abduction recovery was selected for this report (Fig. 5.). The other 11 patients of the original 21 had unilateral (4 patients) or bilateral (2 patients) abduction recovery or failed to have any motion recovery (5 patients) during the 1-year interval indicating an entirely distinct clinical and physiological state as compared to the 10 with unilateral or bilateral adductor recovery.

In the 10 patients with isolated adductor recovery (with no abductor function detected), functional status was assessed preoperatively (as possible), one-week and one year after EAAL. Laryngeal electromyography (LEMG) of the vocal folds was performed on the 12th postoperative month to examine the neurophysiologic basis of the glottic movements. Preoperative respiratory and voice assessment was not feasible due to severe dyspnea or orotracheal intubation in 4 cases of the 10 patients. Statistical analysis (ANOVA) was performed with SigmaPlot 13 scientific graphing and statistical analysis software (Systat Software Inc, CA, USA).

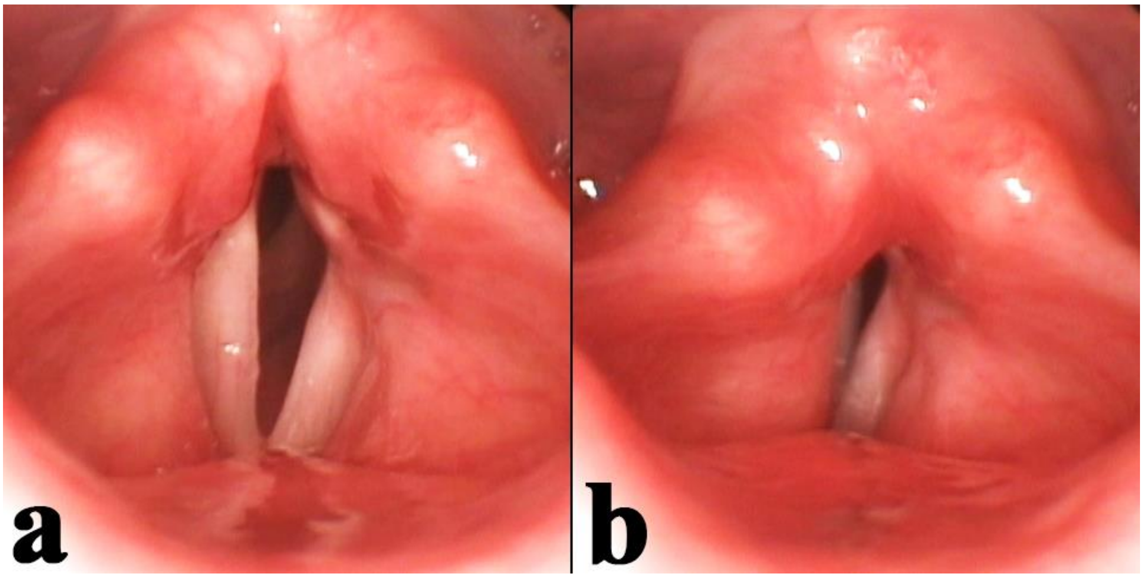


**Figure 5. Recovery of right vocal fold volitional adduction after bilateral vocal fold paralysis treated with left-sided endoscopic arytenoid abduction lateropexy with the ability to cross the midline.** (patient #6, postoperative 12th month, endoscopic view)

a) wide glottis during inspiration

b) cross midline adduction of the right vocal fold

### 5.2.2. Voice assessment

Voice assessment was performed according to our previously published protocol and was based on the guidelines published by the Committee on Phoniatrics of the European Laryngological Society [58].

*Speech recording*

Voice samples were recorded with a high sensitivity (40Hz-16 kHz) condenser head microphone (Audio-Technica ATM 73 ac; Audio-Technica Corporation, Tokyo, Japan). The patients were in a straight sitting position. The head mounted microphone was placed at 45 degrees to the corner of the mouth, 5 cm from the skin. The acoustic data were obtained by having three samples of a sustained /a:/ at a comfortable pitch/loudness spontaneously chosen by each patient and lasting approximately 3 seconds. Three samples of standardized connected-speech were also recorded. All recordings were digitally collected within a sound-insulated room and were transformed to a “wav” file format at a sampling frequency of 96 kHz, using a 24 bit external soundcard (Tascam US 122MkII; TEAC Corporation, CA, USA).

*Acoustic and aerodynamic measurements*

Sustained /a:/ voices were analyzed using the segment from 0.50 to 2.00 seconds for each sample. The averages derived from three samples of each phonation of each patient served as the basis for the analysis. Jitter %, shimmer %, fundamental frequency ($F_0$), harmonics to noise ratio (HNR) and maximum phonation times (MPT) were analyzed using Praat® 5.3.37 software (www.praat.org).

*Subjective self-evaluation*

To assess the patients' voices related to their quality of life, the Hungarian version of the Voice Handicap Index (VHI), was used [59]. The questionnaire contains 30 items in 3 subscales (10 items in each subscale; functional, emotional, and physical). Answers were given in a 5-point scale ranging from 0 (never) to 4 (always). The overall VHI score (raw score) can be used to grade subjective handicap from no handicap (raw score, 0–14), mild handicap (raw score, 15–28), moderate handicap (raw score, 29–50), and to severe handicap (raw score, 51–120) [60].

*Complex, calculated linear index for evaluation of dysphonia*

The Dysphonia Severity Index (DSI) was used in the study to measure the overall quality of the voicing [61]. The DSI is designed to establish an objective and quantitative measurement of the perceived voice quality to assess the efficacy of therapy among dysphonic patients. The index is based on the weighted combination of objective acoustic and aerodynamic parameters, based on objective measures. DSI = (0.13xMPT) + (0.0053xHighest Frequency) – (0.26xMinimum Intensity) – (1.18xJitter %) + 12.4. A normal voice $^{>}/_{=}$ 5 and a severely dysphonic voice scores $^{<}/_{=}$ –5.

*Friedrich dysphonia index*

To evaluate the results, we also used the dysphonia index developed by Friedrich [62]. This index assesses hoarseness (G value from GRBAS scale), frequency range, dynamic range, maximum phonation time, and impairment of communication (from VHI). For each category, a score ranging from 0 (normal) to 3 (severe) is assigned. The mean value of these scores is used to grade the dysphonia.

### 5.2.3. Respiratory assessment

Peak inspiratory flow (PIF) is one of the characteristic and commonly used inspiratory parameters which describes the efficacy of glottis enlarging procedures [63]. Spirometric measurements were performed by using a Thor Spirotube®- PC spirometer (THOR Laboratories Kft., Székesfehérvár, Hungary). 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 [64].

### 5.2.4. Assessment of vocal fold movement

*Indirect endoscopy*

Vocal fold movement recovery was assessed by telescopic laryngoscopy using a 70° rigid endoscope (Karl Storz SE & Co. KG, Tuttlingen, Germany) with the aid of topical anesthesia (tetracaine) sprayed into the oropharynx. The videos were analyzed by two laryngologists. The samples were presented in a random order with respect to surgery and blinded with respect to the patient’s identity. The capacity for vocal fold adduction was evaluated on each side: none: 0, minimal: 1, normal: 2, able to cross the middle line: 3.

*Laryngeal electromyography*

Standard transcutaneous laryngeal electromyography was performed according to the guidelines of the European Laryngological Society on the side of the larynx, in which the adduction movements were visible more definite [18,20]. A NIHON KOHDEN Neuropack X1 EMG system (Nihon Kohden Corp., Tokyo, Japan) with concentric needle electrodes (50mm x 26G, 37mm x 26G; Teca elite, disposable concentric needle electrodes, Natus Neurology, CA, USA) were used for the measurements. The data was analyzed with a MATLAB R2016a (The MathWorks Inc., Natick, MA, USA) and Audacity 2.1.3 software (http://audacityteam.org) by a group of three physicians specialized in laryngeal electrophysiology [42]. The thyroarytenoid (TA) and the posterior cricoarytenoid muscles (PCA) were successfully examined by LEMG in 10 and 8 patients, respectively. The following characteristics were evaluated: insertional activity (none: 0, reduced: 1, normal: 2, increased: 3); pathological spontaneous activity such as fibrillation potentials, myotonic discharges, complex repetitive discharges and fasciculations (none: 0, sparse: 1, clear: 2, strong: 3); Volitional activity (none: 0, single fiber activity: 1, very reduced: 2, mildly reduced: 3, dense interference pattern: 4). In addition, in the PCA and TA, activity indicative of aberrant reinnervation known as “synkinesis” during volitional vocal fold movement was recorded. In this context, a voicing or sniffing gesture would produce the opposite motor unit action potentials (MUAP) pattern than that which is expected; if present (none: 0, sparse: 1, clear: 2, strong: 3). Examples of synkinesis include volitional firing of MUAP’s in the PCA when phonation was being produced and, vice-versa, with MAUP’s in the TA when deep respiration or sniffing gestures were performed.

## 5.3. Results

### 5.3.1. Endoscopic results

During the one-year follow up, 18 vocal folds showed adduction movements (Table I.). In 8 of 10 patients, the non-lateralized vocal fold showed complete or over-adduction. In patient #2 and #3 clear, though incomplete adduction was seen in the non-lateralized side. Two patients had more movement at a year in the lateralized side than in the unoperated side (patient #2 and #9). In those patients, the lateralized side crossed the midline to contact the other cord. In total, 8 of the 10 lateralized cords could visibly adduct at the end of one year.

| Patient Age/Sex | From BVFP to EAAL | Vocal fold | Adduction |
|---|---|---|---|
| #1/52/f | 2 months | Right | 3 |
| | | Left | 1 |
| #2/46/f | 1 day | Right | 3 |
| | | Left | 1 |
| #3/65/f | 3 days | Right | 1 |
| | | Left | 1 |
| #4/39/f | 3 months | Right | 3 |
| | | Left | 1 |
| #5/75/m | 4 months | Right | 3 |
| | | Left | 0 |
| #6/35/f | 1 month | Right | 3 |
| | | Left | 1 |
| #7/68/f | 2 days | Right | 3 |
| | | Left | 1 |
| #8/34/f | 1 month | Right | 3 |
| | | Left | 2 |
| #9/71/f | 1 day | Right | 2 |
| | | Left | 3 |
| #10/64/f | 2 months | Right | 3 |
| | | Left | 0 |

**Table I. Data of BVFP patients with adduction recovery** (1 year postoperative)
The lateralized vocal fold is marked with gray. Third column: grade of endoscopically detected adduction movement per vocal fold. 0: no adduction, 1: mild adduction, 2: complete adduction, 3: adduction beyond the middle line of the glottis. f = female, m = male

### 5.3.2. Laryngeal electromyography results

The results of laryngeal electromyography (LEMG) are presented in Table II. Volitional motor unit action potential (MUAP) activity of the thyroarytenoid muscle was observed in 8 of 9 cases with differing intensities during phonation; however, the interference pattern of the MAUP's was dense (and "normal") in only two cases. In the same muscle, MUAP's indicating synkinesis were detected in five cases; this means that there was increased electrical activity during inspiration. Nonetheless, the ordinal scale of LEMG detection and degree of movement seen on endoscopy was correlative with only one exception (patient #2).

| Patient Age/Sex | Vocal fold | Muscle | Insertion activity | PSA | Volitional activity | Synkinetic activity |
|---|---|---|---|---|---|---|
| #1/52/f | Right | TA muscle | 2 | 0 | 3 | 3 |
| | | PCA muscle | 1 | 0 | 0 | 0 |
| #2/46/f | Right | TA muscle | 2 | 0 | 4 | 0 |
| | | PCA muscle | 2 | 0 | 3 | 3 |
| #3/65/f | Right | TA muscle | 3 | 2 | 0 | 0 |
| | | PCA muscle | 2 | 0 | 1 | 2 |
| #4/39/f | Right | TA muscle | 2 | 0 | 4 | 3 |
| | | PCA muscle | 2 | 0 | 1 | 0 |
| #5/75/m | Right | TA muscle | Data not obtained | | | |
| | | PCA muscle | Data not obtained | | | |
| #6/35/f | Right | TA muscle | 2 | 1 | 2 | 0 |
| | | PCA muscle | 2 | 0 | 1 | 0 |
| #7/68/f | Right | TA muscle | 2 | 1 | 2 | 1 |
| | | PCA muscle | Data not obtained | | | |
| #8/34/f | Right | TA muscle | 2 | 1 | 3 | 1 |
| | | PCA muscle | 2 | 0 | 3 | 2 |
| #9/71/f | Left | TA muscle | 1 | 0 | 1 | 2 |
| | | PCA muscle | 0 | 0 | 2 | 1 |
| #10/64/f | Right | TA muscle | 2 | 0 | 3 | 0 |
| | | PCA muscle | 2 | 0 | 2 | 2 |

**Table II. Results of laryngeal electromyography 1 year after recurrent laryngeal nerve injury.**

m. TA: thyroarytenoid muscle; m. PCA: posterior cricoarytenoid muscles; Insertional activity: 0: none, 1: reduced, 2: normal, 3: increased; Pathological spontaneous activity (PSA): none: 0, sparse: 1, clear: 2, strong: 3; Voluntional activity: none: 0, single fiber activity: 1, very reduced: 2, mildly reduced: 3, dense: 4; Synkinetic activity: none: 0, sparse: 1, clear: 2, strong: 3. f = female, m = male

In 7 of 8 cases, volitional (appropriate) MUAP activity was detected in the PCA (2 were not recorded because could not tolerate LEMG exam of the PCA in one case and of any muscle in a second case). A dense interference pattern was not detected in any of them. No visible abduction was seen in any of the larynges of these patients (this was an inclusion criterion). The mean degree of appropriate MUAP activity was 1.6 based on the scale. The same patients' mean MUAP for the TA muscle is 2.5 +/- 1.3. Synkinetic MUAP activity of the PCA muscle (increased electrical activity during phonation) was detected in 5/8 cases.

### 5.3.3. Respiratory results

All 10 patients showed objective and immediate airway improvement after unilateral endoscopic arytenoid adduction (EAAL). The average PIF increased significantly immediately from 1.01 to 2.04 l/sec. (change 1.03 l/sec., 201.95% of baseline; $p<0.001$). This parameter has increased later to average of 2.49 l/sec. [Fig. 6.a]. The significant improvement of quality of life (QoL) scores also showed the patients' improved satisfaction with their respiratory function [Fig. 7.a]. The average score improved in the early postoperative period from 18.6 to 14.2, then further improved to 10.7 ($p < 0.001$).

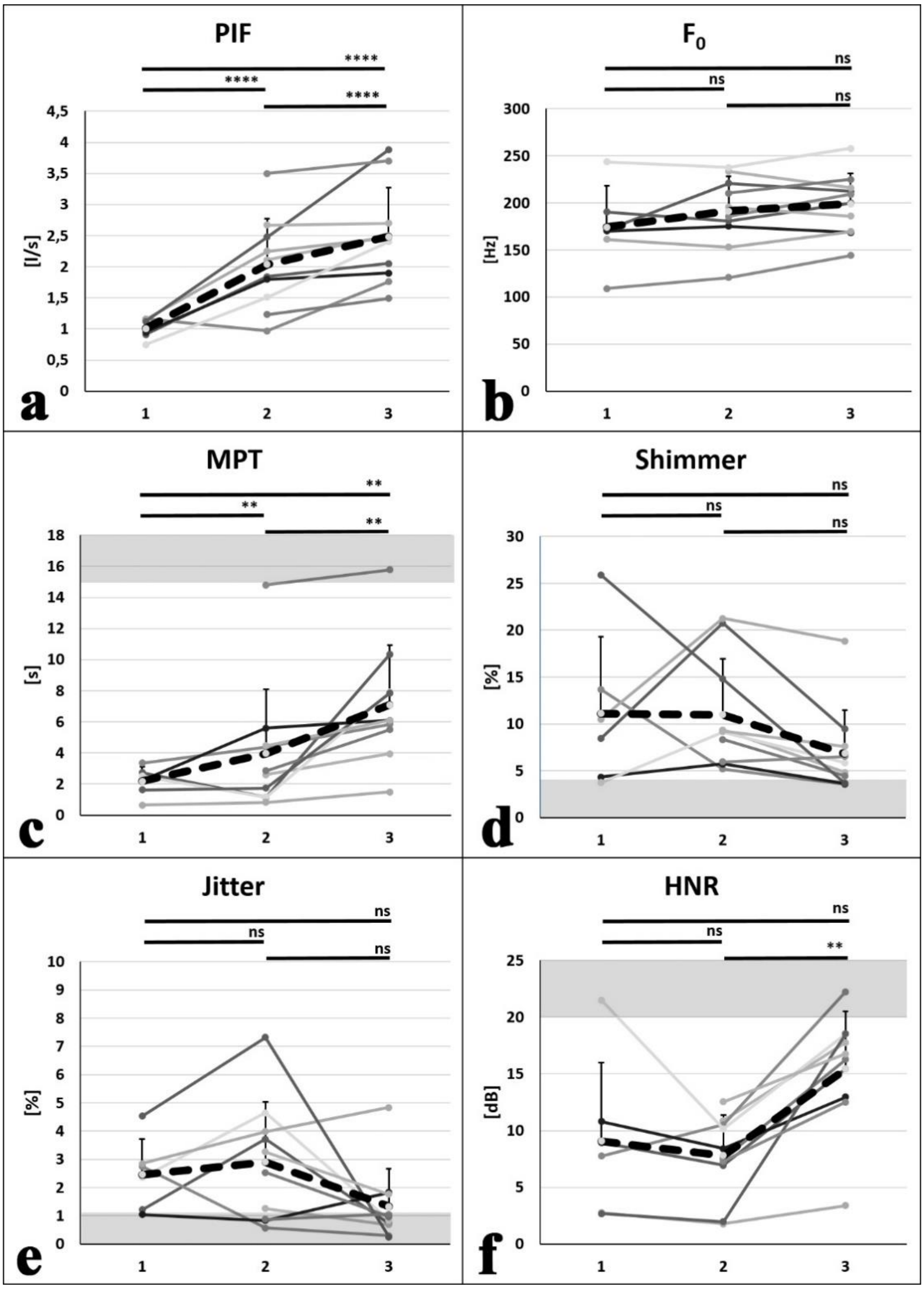


**Figure 6. Objective respiratory and voice results after unilateral endoscopic arytenoid abduction lateropexy in BVFP patients with adduction regeneration.**

Thin lines represent the changing of the individual values, the thick-dashed lines demonstrate the average of the values. The gray area represents the normal range of values. (1: preoperative measurement, 2: 1st postoperative week, 3:1st postoperative year, $*p \le 0.05$, $**p \le 0.01$, $****p \le 0.001$)

a) Peak inspiratory flow (PIF, significant improvement)
b) Fundamental frequency (F0, non-significant change)
c) Maximum phonation time (MPT, significant improvement)
d) Shimmer (non-significant improvement)
e) Jitter (non-significant improvement)
f) Harmonics-to-noise ratio (HNR, significant improvement)

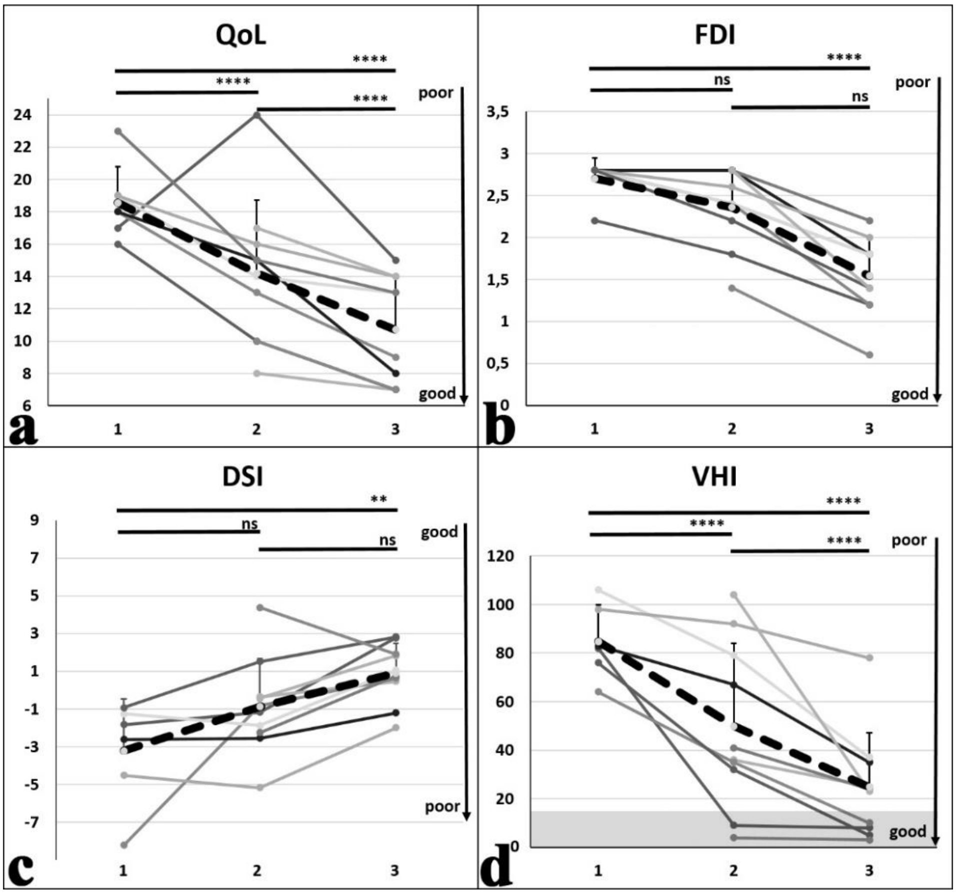


**Figure 7. Results of subjective respiratory and complex voice analysis panel after unilateral endoscopic arytenoid abduction lateropexy in BVFP patients with adduction regeneration.** Thin lines represent the changing of the individual values, the thick-dashed lines demonstrate the average of the values. The gray area represents the normal range of values. (1: preoperative measurement, 2: 1st postoperative week, 3: 1st postoperative year year, $*p \leq 0.05$, $**p \leq 0.01$, $****p \leq 0.001$)

a) Quality of Life score (QoL, significant improvement)
b) Friedrich dysphonia index (FDI, significant improvement)
c) Dysphonia Severity Index (DSI, significant improvement)
d) Voice Handicap Index score (VHI, significant improvement)

### 5.3.4. Voice results

The average fundamental frequency of the 10 patients slightly increased in the early and the more in the late postoperative period (109.77% of baseline and 114.09% of baseline respectively) [Fig. 6.b]. The average maximum phonation time (MPT) improvement was 1.78 sec. in the early postoperative period. It increased significantly to 7.08 sec. [Fig. 6.c] in parallel with the improving vocal fold movements. The value of shimmer showed continuous improvement and decreased to within the physiological range (</= 6.84%) [Fig. 6.d]. Jitter and harmonic to noise ratio (HNR) slightly deteriorated right after surgery, but HNR increased significantly (p<0.01) during the regeneration phase compared to the early postoperative period. Jitter showed notable improvement as well, but this did not reach statistical significance [Fig. 6.e, f]. The complex voice analysis panels verified the improvement of the voice in general. The Friedrich and the Dysphonia Severity Index (DSI) (non-significantly) improved immediately after EAAL but showed further improvement with the regeneration process. Significant improvement (FDI: p<0.001; DSI: p<0.01) was found between the preoperative and late postoperative values [Fig. 7.b,c]. The Hungarian Voice Handicap Index (VHI) demonstrated that patients subjectively also found their voices improved [Fig. 7.d]. The average score decreased significantly from 84.9 to 49.9, then to 24.8 (decrease of 59.5 in total; p<0.001).

After the 12-month postop visit, adduction movements were discovered in two of the BVFP patients who were not included in the focus of this study; these were discovered at 14 and 16 months after the nerve injury. In one patient, complete abduction regeneration of the non-lateralized vocal fold was observed in the 22nd postoperative month; this allowed the lateralizing sutures to be removed.

# 6. ENDOSCOPIC ARYTENOID ABDUCTION LATEROPEXY FOR THE COMPLEX RECONSTRUCTION OF THE AIRWAY AFTER TOTAL CRICOIDECTOMY

## 6.1. Introduction

Chondrosarcoma of the larynx is an uncommon tumor, accounting for approximately 0.1% to 1% of all laryngeal neoplasms [65]. Its most frequent variants (95%–99% of cases) are of low- and intermediate-grade disease [66,67]. Laryngeal chondrosarcomas manifest different pathological behaviors compared to other malignancies of the larynx, and thus the treatment of these tumors is different [68,69]. Complete surgical excision with negative margins is the treatment of choice for oncological control [70,71]. The balance between radical resection and the preservation of laryngeal function is crucial. In the case of cricoid chondrosarcoma, how well this can be achieved depends on how much and what part of the cricoid cartilage remains. It is the only complete ring in the cartilage framework of the airway and is key to airway integrity. This makes preservation of function after cricoidectomy an obvious challenge [24].

The difficulty in reconstruction after the loss of the cricoid often leads to total laryngectomy [25,26]. To avoid this, many less radical procedures have been described. Nonetheless, due to the nature of these techniques, the chance of tumor recurrence increases [73,74]. In the case of more radical techniques, like hemicricoidectomy and the few reported cases of subtotal and total cricoidectomy, prolonged stenting is unavoidable. If autografts such as with rib are used, the donor site complications are not rare. Stenosis is a common risk [75,76].

## 6.2. Materials and methods

### 6.2.1. Patients

In four consecutive patients, total cricoidectomy was performed in three patients (#1, 2, and 4), and subtotal cricoidectomy was performed in one patient (#3). All had low-grade chondrosarcoma of the cricoid cartilage. In all cases, magnetic resonance imaging or computed tomography (CT) imaging demonstrated a round cystic lesion of the posterior lamina of cricoid cartilage. The cortical layer of the cartilage was infiltrated by the tumor in case #1, 2, and 4. In the third case, the lesion infiltrated the first tracheal cartilage and the lower quarter of the thyroid cartilage on the ipsilateral (left) side. The maximum diameters of the tumors were 4.5, 3.0, 2.0, and 4.5 cm (cases #1, 2, 3, and 4), respectively. None of the patients had cervical or mediastinal adenopathy or findings of distant metastases. Patient data is reported in Table III.

| | Patient 1 | Patient 2 | Patient 3 | Patient 4 |
|---|---|---|---|---|
| Age (year) | 59 | 35 | 30 | 64 |
| Gender | Male | Male | Female | Male |
| Maximum diameter of the tumor (cm) | 4.5 | 3.0 | 2.0 | 4.5 |
| Extension of the tumor | Cricoid cartilage | Cricoid cartilage | Cricoid cartilage, 1st tracheal cartilage, lower quarter of the thyroid cartilage on the left side | Cricoid cartilage, retropharyngeal space, prevertebral fascia, oesophageal introitus |
| Mobility of the vocal cords | Bilaterally slightly impaired | Normal | Normal | Bilateral complete immobility |
| Previous surgery | – | – | – | Hemicricoidectomy, right-sided arytenoidectomy, partial resection of the right thyroid lamina |
| Cricoidectomy | Total | Total | Subtotal/right part of the cricoid lamina | Total |

**Table III. Patient data and type of the surgery**

The first three patients presented with progressive dysphonia and dyspnea that had started at least 4 months prior to their diagnosis. Vocal fold mobility was normal in the second and third cases. The first case had slightly impaired mobility. The fourth patient was tracheostomy-dependent and was referred to the authors after tumor recurrence despite multiple laryngeal surgeries and external beam radiation therapy. Hemicricoidectomy, partial resection of the right thyroid lamina, and right-sided arytenoidectomy were previously performed. The tumor recurrence was spreading into the retropharyngeal space, infiltrating the surrounding soft tissues and extending to the prevertebral fascia. Preoperative endoscopy revealed complete immobility of both vocal folds.

### 6.2.2. Surgical technique

All operations were performed under general anesthesia through a horizontal incision made at the level of the cricoid cartilage. The trachea was bluntly dissected from larynx to superior mediastinum, protecting the recurrent laryngeal nerves and great vessels. Isolating the tumor, the cricothyroid and cricotracheal ligaments and the inferior horns of the thyroid cartilage were transected (Figure 8.a). In the cases of total cricoidectomy (cases #1, 2, 4) the posterior and lateral cricoarytenoid muscles were sacrificed. The cricoid cartilage was dissected at the cricotracheal ligament and then completely removed together with its outer perichondrium (Figure 8.b). The pharyngeal constrictor muscle and the esophagus were carefully dissected from the cricoid and the rest of the tissue to be resected. Then a low, inferior tracheotomy was performed through a separate skin incision below the fifth tracheal cartilage. The orotracheal tube was replaced there (cases #1, 2, 3); in patient #4, it was repositioned to this distal location from the existing tracheostomy.

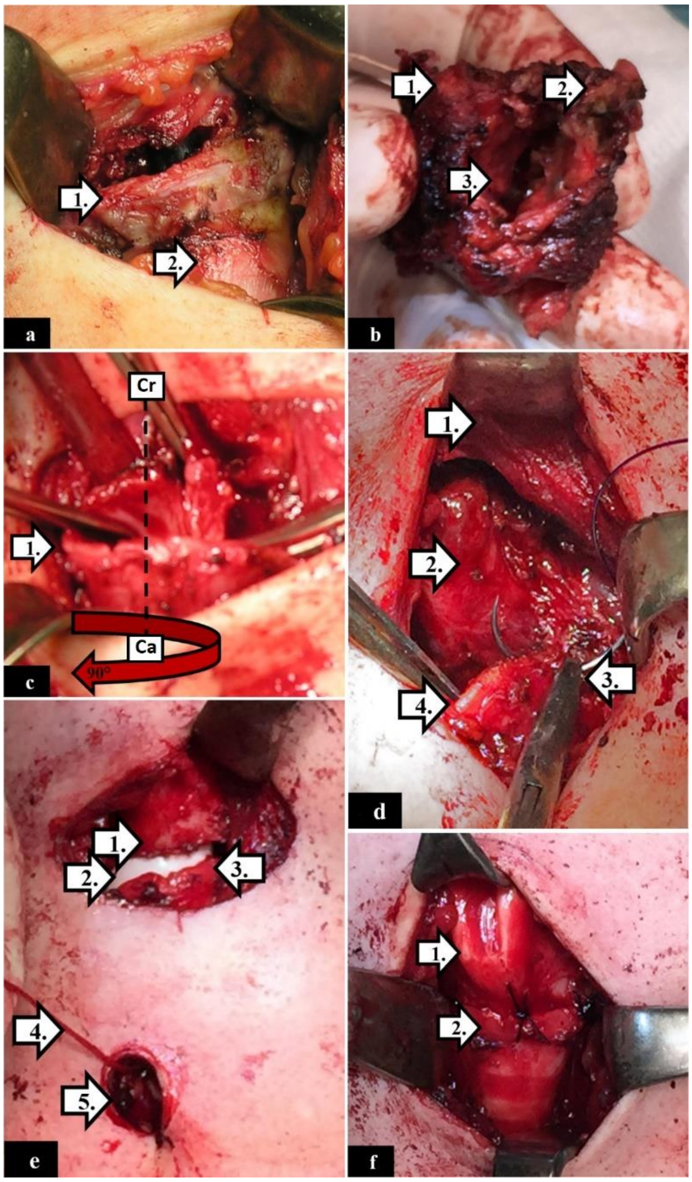


**Figure 8**. **Resection of the cricoid cartilage and reconstruction of the airway**

a) The explored cricoid cartilage. 1: the cricoid cartilage, 2: the first tracheal ring
b) The completely removed cricoid cartilage. 1,2: the articular surface of the cricoarytenoid joint, 3: the inner surface of the trachea is infiltrated by the tumor
c) The rotated tracheal trunk. 1: the trachea is rotated clockwise approximately by 90°. Cr-Ca: cranio-caudal axis
d) The fixation of the rotated tracheal trunk. 1: the thyroid cartilage is retracted, 2: the anterior wall of the esophagus, 3: the right part of the rotated trachea will be sutured to the left posterior part of the lower edge of the thyroid cartilage, 4: the posteriorly rotated midline of the trachea
e) The soft stent in the reconstructed larynx. 1: the inferior edge of the thyroid cartilage, 2: the soft stent, 3: the first rotated tracheal cartilage, 4: fixing thread of the soft stent, 5: inferior tracheostomy
f) The reconstructed cartilage framework of the larynx. 1: the remnant of the thyroid cartilage, 2: the rotated first tracheal cartilage

*Resection variations in specific cases*

In the first patient, the articular surface of the arytenoid cartilages had to be resected due to the massive extension of the lesion. In the third patient, the first two tracheal rings and the lower part of the thyroid cartilage were also resected below the ipsilateral vocal fold on the left side (Figure 9.a,b). In the fourth patient, a hemipharyngectomy, a partial resection of the esophageal introitus, and an expanded resection of the surrounding soft tissues were also performed.

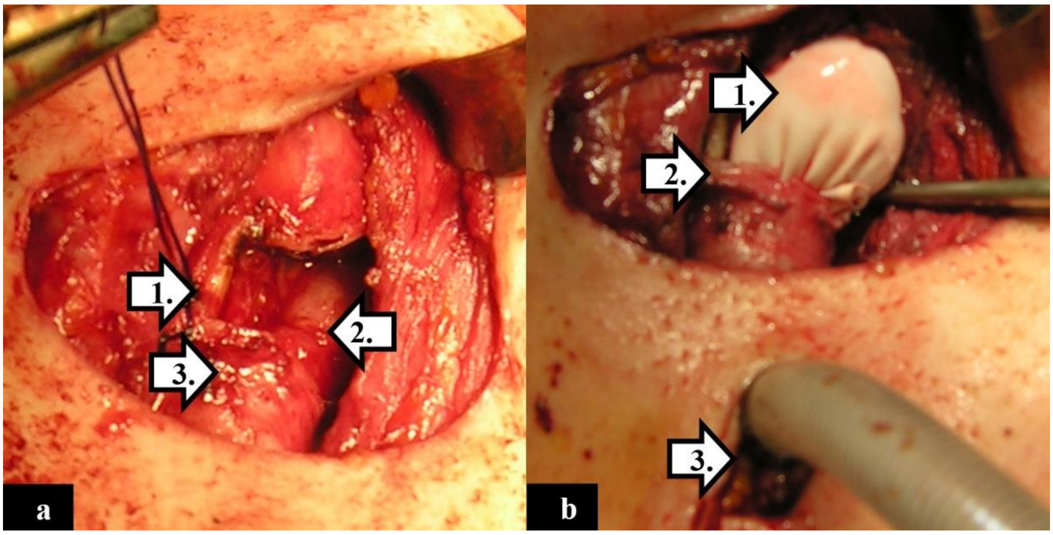


**Figure 9. Extension of the resection** (patient #3)

a) 1: the left side of the the thyroid cartilage is resected under the level of the vocal fold, 2: the left pyriform sinus, 3: the third rotated tracheal ring
b) 1: soft stent, 2: the third rotated tracheal ring, 3: distal tracheostomy

*Laryngotracheal anastomosis*

The distal trachea was mobilized until it could be easily pulled up to the level of the thyroid cartilage. The trachea was then rotated clockwise (looking at the trachea from above) by about 90 degrees for the anastomosis (Figure 8.c) simply because it is easier for a right-handed surgeon. In case 3, where the right side of the cricoid lamina with the right arytenoid remained after the resection, the tracheal trunk was rotated counter-clockwise to complete and support the resected part of the cricoid ring. The right posterolateral edge of the proximal tracheal cartilage was sutured to the left posterior part of the thyroid cartilage with absorbable suture (0-PDS, needle: 26 mm, 1/2 circle, round-bodied, Ethicon, Somerville, NJ) (Figure 8.d, 10.a). These massive holding threads fixed the laryngotracheal anastomosis during the healing period, and the robust needle was necessary for penetration through the rigid thyroid lamina. A second suture was placed on the opposite corner of the thyroid cartilage (the right posterior corner); thus, the trachea was fixed to the thyroid lamina on both sides rotated by approximately 90 degrees. This formed a complete ring, thereby replacing the structure of the missing cricoid cartilage.

In the next step, the arytenoid and interarytenoid mucosa were separately sutured (Vicryl 2.0, Ethicon) to the posteriorly rotated side (formerly the right side) of the trachea (Figure 10.b). Then a soft stent (silicon tube filled with gauze) was placed into the airway cavity within the reconstruction to promote better healing with less cicatricial scarring of the mucosa. This also served to stabilize the arytenoids in their abducted position (Figure 9.e, 9.b). The lower arch of the thyroid cartilage and the anterior (previously left) side of the trachea were sutured with four to five interrupted sutures. In summary, a modified thyrotracheopexy was performed in which the anterior wall of the subglottic part of the larynx was reconstructed with the left side of the trachea, and the posterior wall was reconstructed with the right side. The new tracheostomy was intubated with a cuffed tracheal cannula at the end of the surgery. Parenteral ceftriaxone (Ceftriaxone Kabi; Frensenius Kabi Hungary, Hungary, Budapest) and metronidazole (Klion; Richter Gedeon, Hungary, Budapest) antibiotics were administered in all cases at least for 7 days.

This procedure ensured a sufficiently wide subglottic space. However, the glottic aperture was not intrinsically assured. In cases of total cricoidectomy, the lack of the muscles attached to the arytenoid cartilages caused the prolapse of the interarytenoid mucosa and the passive adduction of the vocal folds after removing the soft stent. Therefore, a second operation was performed involving a unilateral (case #4) or bilateral (cases #1, 2) arytenoid lateropexy with a special endolaryngeal thread guide instrument (ETGI; Mega Kft, Szeged, Hungary) [31,32] (Figure 11.). In the same surgery (cases #2, 4), the edema of the supraglottic soft tissue and interarytenoid mucosa was reduced by Ultra Dream Pulse (UDP) CO2 laser (DS-40U, Daeshin Enterprise, Seoul, Korea).

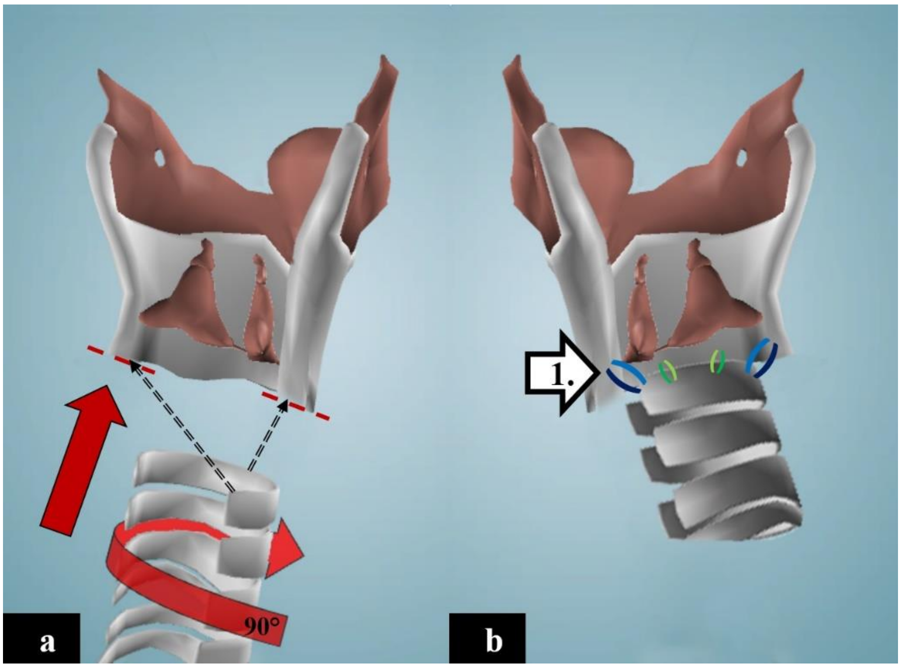


**Figure 10. 3D model of the reconstruction**

a) The tracheal cartilage is pulled up and is rotated clockwise approximately by 90°. The inferior horns of the thyroid cartilage are resected. The dashed black lines indicate the fitting points of the reconstruction.
b) The posteriorly rotated right side of the trachea is sutured to the thyroid cartilage and to the arytenoid and interarytenoid mucosa; 1: the posterior suture line; blue: main fixation sutures (PDS 0.0), green: the arytenoid and interarytenoid mucosa is sutured to the posteriorly rotated side of the trachea (Vicryl 2.0).

### 6.2.3. Functional evaluation and follow-up care

The voice samples were recorded with a high sensitivity (40Hz–16kHz) condenser head microphone (Audio-Technica ATM75) at a sampling frequency of 96 kHz, 24 bit (Tascam US 122MkII external soundcard) and analyzed by Praat 5.3.2.9. software (www.praat.org). The following acoustic parameters were recorded in this study: mean fundamental frequency, jitter, shimmer, harmonics-to-noise ratio, and mean phonation time. Each patient was invited to fill out the Hungarian version of Voice Handicap Index (VHI) questionnaire [59,77]. 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 [64]. Paying special attention to the swallowing problems, the patients also completed the Swallowing Quality of Life questionnaire (SWAL-QOL) by McHorney [78]. Spirometric measurements were performed by using a THOR Laboratories Kft., Szekesfehérvar, Hungary. Peak inspiratory flow was registered in all cases [63,79]. The status of the postoperative airway was investigated by high-resolution three-dimensional CT reconstruction. Follow-up evaluations included systematic endoscopic and radiological examinations (Figure 11.a,b; 12).

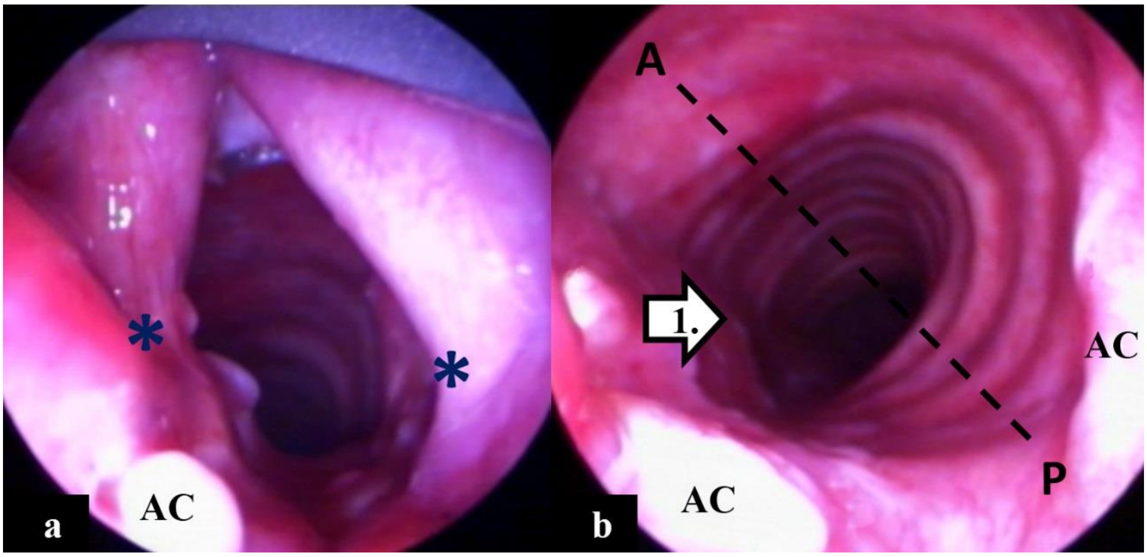


**Figure 11. Postoperative endoscopic view** (patient #1)

a) A properly wide glottic gap was achieved by bilateral arytenoid lateralization; *: position of the sutures of the arytenoid lateralization; AC: arytenoid cartilage
b) A wide subglottic space was formed by the reconstruction; 1: the membranous wall of the trachea, *: position of the sutures of the arytenoid lateralization, (the anteroposterior axis is marked by the dashed line); AC: arytenoid cartilage

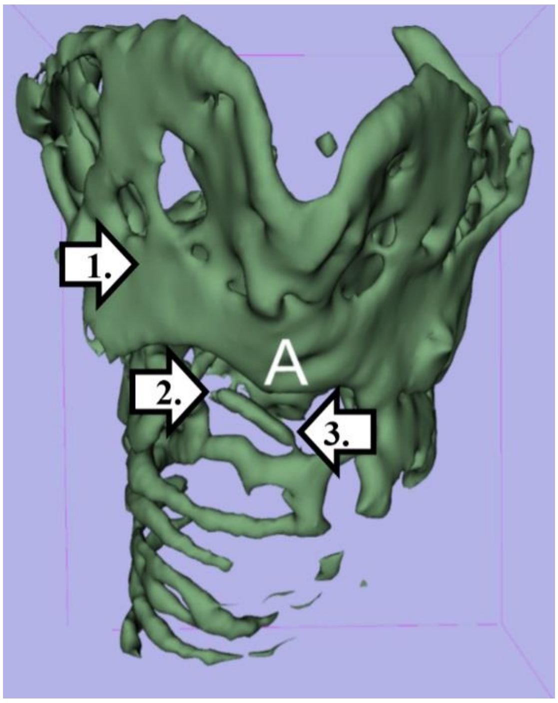


**Figure 12. 3D CT reconstruction of the laryngeal framework** (patient #2, 6th postoperative month, sagittal view)
1: the remnant of the thyroid cartilage, 2: the cricoid cartilage is resected, 3: the rotated tracheal rings

## 6.3. Results

No major perioperative or postoperative complications occurred. Tumor-free margins were proven by histology in all cases. The laryngeal soft stents (patient #2,3,4) were removed during direct laryngoscopy with general anesthesia on the 9th, 6th, and 12th postoperative day, respectively. Events of the early postoperative period are shown in Table IV. Endoscopic arytenoid lateropexy was performed in cases of total cricoidectomies (patient #1,2,4) on the 14th, 9th, and 12th postoperative day, respectively. The edema of the false vocal folds was also reduced by UDP $CO_2$ laser in the same session. Edema of the supraglottic region was also reduced by laser in the third patient on the 39th postoperative day. In the second case, re-opening of the closed tracheostomy was necessary for one day due to safety reasons 7 weeks after the surgery. Speech ability was preserved in all cases. Functional results are shown in Table V. Oral feeding was allowed for the first and third patient from the 9th postoperative day. Nasogastric feeding tube was used in the second patient for 20 days. The first three patients were able to tolerate a normal diet. The fourth patient, who had a partial pharyngectomy, was able to swallow saliva, but remained gastrostomy-dependent throughout the follow-up period (9 months). During the follow-up time (39, 18, 17, 9 months, respectively), the patients were free from local and distant recurrences.

| | Patient 1 | Patient 2 | Patient 3 | Patient 4 |
|---|---|---|---|---|
| Removing of the soft stent (postoperative day) | No stenting | 9 | 6 | 12 |
| Additional intervention (postoperative day) | Bilateral EAAL | Bilateral EAAL<br>Edema reduction with UDP laser | Edema reduction with UDP laser | Unilateral EAAL<br>Edema reduction with UDP laser |
| | 14 | 9 | 39 | 12 |
| Decannulation (postoperative day) | 14 | 20 | 6 | 17 |
| Oral feeding (postoperative day) | 9 | 20 | 9 | Gastrostomy-dependent |

**Table IV. Postoperative care after total/subtotal cricoidectomy.** UDP: Ultra Dream Pulse, EAAL: endoscopic arytenoid abduction lateropexy.

| | Patient 1 | Patient 2 | Patient 3 | Patient 4 | Physiological Values |
|---|---|---|---|---|---|
| Mean fundamental frequency (Hz) | 98,46 | 134,9 | 150,1 | 86,65 | Female: 155–334; male: 85–196 |
| Mean phonation time(s) | 4,12 | 2,39 | 3,55 | 2,91 | 10–20 |
| Jitter (%) | 7,45 | 9,36 | 9,65 | 8,05 | < 1.04 |
| Shimmer (%) | 20,86 | 19,97 | 19,47 | 15,24 | < 3.81 |
| Harmonics-to-noise ratio (dB) | 1,86 | 4,6 | 0,48 | 2,17 | 20 < |
| Voice Handicap Index | 14 | 51 | 20 | 25 | Min: 0; max: 120 |
| Peak inspiratory flow L/min) | 108 | 134,4 | 90 | 83,4 | – |
| Quality of Life | 9 | 14 | 10 | 12 | Min: 6; max: 25 |
| SWAL-QOL | 212 | 167 | 200 | Gastrostomy-dependent | Min: 44; max: 220 |
| Follow-up (month) | 38 | 17 | 16 | 8 | |

**Table V. Functional Results** SWAL-QOL: Swallowing Quality of Life.

# 7. DISCUSSION

## 7.1. Introduction of laryngeal electromyography into clinical practice

LEMG patterns of vocal fold immobility with neurological origin are typical and well recognizable. Pathologic spontaneous activity, polyphasic potentials, neuropathic interference patterns are specific for neural injury and suggest paresis or paralysis. The result of the LEMG allows us to draw conclusions about the prognosis of the neural injury. Lack of pathological spontaneous activity, normal/almost normal motor unit potentials and mildly reduced interference pattern usually means good prognosis with potential functional reinnervation. In contrast, pathological spontaneous activity, decreased or missing recruitment means poor prognosis [16].

The reinnervation of the laryngeal muscles is a complex and precarious process. The main problem is that adductor and abductor fibers will be mixed in the injured nerve section during regeneration and this miscellaneous innervation decreases the effectivity of the volitional movements. This counter-productive reinvention can be attributed to mild residual symptoms (e.g. slight hoarseness, effort dyspnea) but also for severe dysfunctions that often mimics the situation of complete laryngeal paralysis. Such aberrant reinnervation is also called synkinetic regeneration. Since in these cases there is more or less volitional electric activity in both the abductor and adductor muscles during inspiration and phonation as well, LEMG alone cannot distinguish between functional and counterproductive reinnervation [16]. This is the explanation that endoscopic findings of vocal fold paralysis don't always correspond to the assumed prognosis in LEMG. According to meta analyzes, LEMG can safely determine the adverse outcome of reinnervation but, despite potentially favorable LEMG signals, clinically detected reinvention is unclear due to possible synkinetic reinnervation processes. [16,35, 80-83].

The advantages of LEMG are obvious in determining the optimal therapeutic treatment of bilateral vocal fold paralysis. In case of severe dyspnea, if the physiological LEMG finding confirms the existence of a mechanical fixation, (function preserving) glottis widening surgical intervention must be performed as soon as possible [84-86]. If the test proves vocal fold immobility with neurological origin, different strategy should be chosen in accordance with the classical principles. The fact, that the introduction of modern surgical procedures (e.g. intraoperative nerve monitoring) did not significantly reduce the frequency of recurrent laryngeal nerve injuries (mostly by thyroid surgery) complicates the question further. However, the number of reversible paralyses increased [87-89]. Even nowadays, many authors suggest a minimum of 6 months waiting period before the definitive glottis widening surgery (even with temporary tracheotomy that significantly degrade the quality of life) due to the possible spontaneous reinvention [8,87-89]. With the help of LEMG, in the early stage of paralysis, within a few weeks, it is possible to select patients for whom there is no use to wait with the glottic widening surgery due to the severity of neural lesion. In patients with good or uncertain prognosis, potentially reversible glottis widening methods must be preferred as a good alternative to tracheotomy. In the case of bilateral paralysis, LEMG can play a decisive role in defining the side of the glottis widening surgery, as these interventions are desirable in that side, where regeneration is less likely.

Nowadays there is a significant paradigm shift in the surgical treatment of vocal fold palsy. Modern versions of dynamic glottis widening methods are becoming increasingly popular instead of the classic static solutions. The most common of these procedures is the selective reinnervation of the laryngeal muscles via phrenic or hypoglossal nerve. However, these procedures can successfully be performed only if there is no paralysis, but synkinetic activity. This synkinetic activity develops with the amalgation of abductor and adductor nerves. In these cases, the muscular atrophy is negligible due to continuous neural stimulation and the anastomosis of the peripheral nerves can produce effective muscle movement [10, 90]. Instead of the highly complicated reinnervation techniques, laryngeal pacing might be a more favorable solution for these 'synkinetic type' palsy. With this method, the function-synchronous movement of the laryngeal muscles is achieved through an implant and an electrode placed in the muscle. However, motion can only be accomplished if the electrode is inserted near the nerve, which is responsible for the synkinetic reinnervation. The direct stimulation of the muscles is not energy-efficient [91,92]. In these cases, the role of LEMG is also obvious for the selection of the appropriate patients.

## 7.2. Selective recovery of adductor muscle function following recurrent laryngeal nerve injuries

According to evolutionary theory, the most primitive larynx can be found in the *Polypterus bichir,* also known as "the lungfish", which inhabits the Nile River [93]. The larynx of this fish consists simply of a muscular sphincter to protect the lower airway from the intrusion of foreign matter (mainly water in this case). It does not exhibit active muscular dilatation during respiration. Neither does it have any phonatory function, which is considered the "third function" of the homologous mammalian larynx [93,94]. Though not definitive, these data support the potential that the human larynx appears designed to default to this same rudimentary sphincter function. In the case of significant injury to the recurrent laryngeal nerves, the vocal folds lie in the flaccid paramedian position absent airflow. This can allow for some degree of respiration if any tone remains and if respiration is not rapid. Phonation is commonly possible but tends to be of low volume and very low efficiency with short maximum phonation times. Lower airway protection is passive and often very limited.

The postinjury equilibrium of adduction and abduction forces clearly changes over time. The complexity of laryngeal innervation (e.g.: Galen's anastomosis, the "human communicating nerve") may be responsible for the residual innervation and may also explain or at least contribute to a significant reinnervation process as well [95-97]. However, reinnervation is frequently synkinetic rather than functional, as Crumley stated [52], which may be based on the braded mixing of axons that serve antagonistic functions. Furthermore, the significant numerical superiority of the adductor muscles fibers and axons leads to preferential reinnervation of adduction muscles and adduction during phonation and breathing as well [54]. Variations in the position and function of the "paralyzed" vocal folds could be dependent on the degree and distribution of intrinsic laryngeal muscle reinnervation and synkinesis. Accordingly, bilateral recurrent laryngeal nerve paralysis generally does not mean a "dead" larynx. Quite the contrary, in most cases, significant volitional adduction can be observed within weeks or months after nerve injury. However, volitional nature of the movements must be confirmed by LEMG.

Volitional motor unit action potential (MUAP) activity of the thyroarytenoid muscle was detected in the majority of the 10 cases during phonation. Despite the frequency of synkinetic activity detection (in 5 of 9 cases), the phenomenon of preferential reinnervation of the adductor muscles as a *functional* outcome is strongly supported by our results. The outcome of this “hybrid” pattern of reinnervation and the resultant vector between the adduction and abduction forces are the basis of an endoscopically obvious volitional adduction motion which enables phonation. The technically more challenging LEMG of the posterior cricoarytenoid muscle was feasible in only 8 of 9 cases. Of the 8, synkinetic activity of posterior cricoarytenoid muscle was detected in 5 of these patients, none of whom were seen to have *functional* or visible abduction. Therefore, while electrical reinnervation of the posterior cricoarytenoid muscle could be demonstrated, it was clearly overpowered by the adduction from TA reinnervation. This emphasizes the need for endoscopic assessment to evaluate glottic function regardless of the LEMG results.

In the case of BVFP, the ultimate goal is the rehabilitation of the all three laryngeal functions, respiration, deglutition and phonation. The conventional “static” glottis widening techniques such as arytenoidectomy or transverse cordotomy do not take advantage of the potential adduction regeneration because they are based on partial or complete resection of the arytenoid cartilage(s) or the vocal fold(s) [8]. In the case of these interventions, dysphagia, aspiration with infectious complications, and hypophonia are a common side effect. In addition, the removal of the interarytenoid mucosa or its post-surgical atrophy, may also increase the risk of aspiration by producing gaps in the protective rim of the laryngeal inlet through which fluids can penetrate the airway.

We propose the strong adduction recovery potential found in the larynx post BVFP, can be used for the generation of active phonation and good airway protection, in parallel with an adequate airway. This is primarily predicated on the use of a minimally invasive glottis widening interventions that do not destroy the voice in the service of airway comfort. During EAAL the entire vocal unit is displaced in a physiological manner without resection of phonatory structures and without consequential scarring. The procedure does not damage the interarytenoid region either, which is essential to safe, aspiration-free swallowing [98]. After the EAAL procedure, the vocal folds become straighter and tenser than after other endoscopic glottis enlarging interventions [31,32]. In addition, the EAAL technique produces a relatively small anterior angle compared to other interventions [32]. This further facilitates better phonatory closure along with improved breathing potential. Prior to this report, these phoniatric advantages were hypothetical and based on our cadaver studies. They can now be considered verified by our phoniatric outcomes.

There are only a few studies in the literature dealing with the voice quality after glottis widening surgical interventions. Compared to the commonly used posterior transverse laser cordotomy, EAAL gives better objective and subjective results. Jitter, shimmer, MPT, VHI, Friedrich index and the Dysphonia Severity Index improved significantly and in parallel with higher peak inspiratory flows (PIF) [99,100]. The improvement in objective and subjective voice quality proves that EAAL does not interfere with the potential regeneration process either. Due to the non-destructive manner of the procedure, it also allows active (over) adduction movements on the untreated vocal fold if adducting reinnervation occurs. Furthermore, the lateralized cords in two cases recovered adduction better than the unoperated side in two patients. This indicates that if reinnervation occurs, even the lateralized side can return to the service of improved glottic function. The inescapable conclusion is that adduction recovery and overcome the traction of the lateralization suture without the associated damage to the phonatory mechanism known to occur with more traditional approaches such as cordectomy and arytenoidectomy.

The late recovery of movement found well after a year, as mentioned in our results, confirm our prior clinical experience that the final state of the reinnervation process in the larynx needs many months or even years to reach finality.

### 7.3. Endoscopic arytenoid abduction lateropexy for the complex reconstruction of the airway after total cricoidectomy

Lesions, requiring partial or total cricoidectomy, mean major challenge regarding the reconstruction of the airway. Since the cricoid ring is the critical structure supporting normal laryngeal function, the poor functional results of the existing reconstruction techniques are not surprising. It can be primarily traced back to two problems. First, the reconstruction of the subglottic airway is difficult with the existing graft options. Second, published methods do not address two issues of airway integrity: the unstable and often denervated arytenoid cartilages and the prolapse of the supraglottic soft tissues into the laryngeal cavity.

Based on our work, the subglottic support that is disrupted by the cricoidectomy can be reconstructed in a stable manner with the rotation of the autologous tracheal advancement flap. The remnant of the thyroid cartilage together with the rotated trachea provide a well-vascularized and mucosa-covered rigid ring. The segmental tracheoesophageal arteries must be transected on the anterior side down to the proximal 3-4 tracheal rings and maintained on the posterior side. Moreover, the transverse intercartilaginous arteries and the lateral longitudinal anastomoses remain intact and provide the basis for a quick, complication-free recovery [101]. Post thyro-tracheopexy, the arytenoid cartilages and the surrounding soft tissues are sitting atop and supported by the rotated tracheal wall. This connection, however, does not prevent the passive adduction of the vocal folds since the cricoarytenoid joints are severed and the articular surface is resected on one or both sides. There are also no attachment points for three of the four muscles that act on the arytenoid bodies. The thyroarytenoid is the only muscle that may still be functionally connected, and it only adducts the vocal fold. This can adversely affect the airway aperture. Endoscopic arytenoid abduction lateropexy can effectively address this problem as it has been already demonstrated in cases of bilateral vocal fold immobility

[22,31,32]. An adequately wide glottic gap can therefore be produced with this minimally invasive procedure after total cricoidectomy.

Swallowing and the prevention of the aspiration are also important issues. In those patients in whom the pharyngeal structures remained intact (#1,2,3), radiologically proven, safe swallowing could be achieved in a reasonable period of time. The results presented confirm that the mucosa of the arytenoid region can be preserved by these techniques. The protecting laryngeal reflex enables an adequate pharyngeal swallowing function despite the impairment of the glottic motions.

A decline of voice quality was inevitable in these patients due to the resection of the arytenoid muscles (#1,2,4). Despite the whispering voice and the relatively low phonation time, a socially acceptable voice was maintained in all patients. While accounting for oncological concerns in radical surgery, it may still be possible to preserve the muscles attached to the arytenoids and the recurrent laryngeal nerve branches. This could lead to higher voice quality by the preserved motion of the vocal folds.

# 8. CONCLUSIONS AND NEW RESULTS

## 8.1. Introduction of laryngeal electromyography into clinical practice

LEMG is a technically complex and highly professional process. However, the new therapeutic methods, the better understanding of the pathophysiology of laryngeal palsy and neural regeneration, the resulting modern surgical concepts, and the correct choice of optimal intervention necessitate the routine use of LEMG in the laryngeal centers. Accordingly, LEMG was introduced in our clinical protocol for the complex diagnosis of vocal fold immobility. We use it for the differentiation of vocal fold motion impairment with mechanical or neurogenic origin. In case of BVFP LEMG helps to choose the appropriate side of larynx to be surgically lateralized. Furthermore, the evaluation of neural injury allows to predict the chance of potential regeneration.

## 8.2. Isolated recovery of adductor muscle function following bilateral recurrent laryngeal nerve injuries

EAAL allows a simple, quasi-dynamic option with parallel phonatory and respiratory improvements. This is accomplished by virtue of generating a passively abducted vocal fold without sacrificing the functional integrity of the glottic aperture. This includes allowing for the potential benefits of active adduction recovery in the vocal folds. The long-held premise, that one or two of the primary functions of the larynx, (voice quality, swallowing safety and/or breathing) must be sacrificed in order to improve the other in BVFP, can now be discarded. We can return a patient to safe comfortable breathing and a functional voice while avoiding iatrogenic aspiration.

## 8.3. Endoscopic arytenoid abduction lateropexy for the complex reconstruction of the airway after total cricoidectomy

The subglottic support that is disrupted by the cricoidectomy can be reconstructed in a stable manner with the rotation of the autologous tracheal advancement flap after partial or even total cricoidectomy.  The remnant of the thyroid cartilage together with the rotated trachea provide a well-vascularized and mucosa-covered rigid ring, thus total laryngectomy can be avoided. EAAL allows the lateralization of the unstable arytenoid cartilages, and supraglottic soft tissues even is case of missing cricoid cartilage. It enables voice preservation and the potential for safe swallowing as well.

# 9. ACKNOWLEDGEMENT

Without help, support, and encouragement from several persons, I would never have been able to complete this work.

First of all, I would like to express my gratitude and thanks to my supervisor, Professor László Rovó for encouraging and supporting my work from the very beginning. As the Head of the Department, he introduced me to clinical work and provided me with the opportunity to begin my scientific career as well. I am deeply indebted to my colleagues, the members of our upper airway stenosis workgroup, especially to Dr. Balázs Sztanó and Dr. Vera Matievics for their cooperative work. Thanks to my colleagues at the Department of Oto-Rhino-Laryngology, Head and Neck Surgery. My thoughts and graduate also go towards my family, wife and friends whose continuous support, encouragement, belief and patience filled me with energy and making everything worthwhile.

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# 11. APPENDIX

**Quality of life' kérdőív felső légúti szűkületes betegek számára**

**Név:** **Dg.:**

- Nehézlégzés
  1. Nincs
  2. Nehéz munkavégzés esetén
  3. Enyhe fizikai megerőltetés esetén is
  4. Nyugalomban
  5. Tracheotomia

- Hangos légzés
  1. Nincs, a légzés hangtalan
  2. Nehéz munkavégzés eseten hangossá váló légzés
  3. Enyhe fizikai megerőltetés esetén is hangos
  4. Nyugalomban
  5. Tracheotomia

- Köhögés
  1. Nincs köhögés
  2. Enyhe köhögés
  3. Erős köhögés
  4. Tracheotomia

- Hangképzési panasz
  1. Normális
  2. Kis fokú beszédzavar (hangos környezetben nehezebben érthető)
  3. Súlyos beszédzavar
  4. Aphonia

- Nyelési panasz
  1. Normális
  2. Kisebb nehézségek, időnkénti félrenyelés
  3. Súlyos nyelészavar

- Elégedettség az állapottal
  1. Teljesen elégedett
  2. Nagyrészt elégedett
  3. Kissé elégedetlen
  4. Elégedetlen

## Hungarian version of the Voice Handicap Index

Név: Diagnózis:

Cím: Telefonszám:

Dátum: Foglalkozás:

**Jelölje meg azt a választ, amely megmutatja milyen gyakran fordulnak elő a következő állítások Önnel!**
**Válaszok: 0 = soha, 1 = elvétve, 2 = néha, 3 = gyakran, 4 = mindig**

| | | | | | | |
|---|---|---|---|---|---|---|
| F1 | A hangomat nehezen hallják meg mások. | 0 | 1 | 2 | 3 | 4 |
| P2 | Ha beszélek, kifulladok. | 0 | 1 | 2 | 3 | 4 |
| F3 | Az embereknek nehéz megérteni engem egy hangos teremben. | 0 | 1 | 2 | 3 | 4 |
| P4 | A hangszínem változik a nap folyamán. | 0 | 1 | 2 | 3 | 4 |
| F5 | A családomnak nehézséget okoz meghallani, ha a házban/ lakásban hívom őket. | 0 | 1 | 2 | 3 | 4 |
| F6 | Kevesebbszer használom a telefont, mint szeretném. | 0 | 1 | 2 | 3 | 4 |
| E7 | Feszült leszek a hangom miatt, ha másokkal beszélek. | 0 | 1 | 2 | 3 | 4 |
| F8 | A hangom miatt hajlamos vagyok arra, hogy a nagyobb társaságokat elkerüljem | 0 | 1 | 2 | 3 | 4 |
| E9 | Az emberek felfigyelnek a hangomra, mert zavaró. | 0 | 1 | 2 | 3 | 4 |
| P10 | Az emberek megkérdezik: „Mi történt a hangoddal?” | 0 | 1 | 2 | 3 | 4 |
| F11 | A hangom miatt ritkábban beszélek barátokkal, szomszédokkal, rokonokkal. | 0 | 1 | 2 | 3 | 4 |
| F12 | Az emberek megkérnek, hogy ismételjem meg azt, amit mondtam. | 0 | 1 | 2 | 3 | 4 |
| P13 | A hangom érdes és fakó. | 0 | 1 | 2 | 3 | 4 |
| P14 | Úgy érzem, meg kell erőltetnem magam, ha a hangomat használom. | 0 | 1 | 2 | 3 | 4 |
| E15 | Úgy érzem, mások nem értik meg a problémámat a hangommal. | 0 | 1 | 2 | 3 | 4 |
| F16 | A nehézségeim a hangommal korlátoznak a magán, és üzleti életben. | 0 | 1 | 2 | 3 | 4 |
| P17 | A hangom érthetősége kiszámíthatatlan. | 0 | 1 | 2 | 3 | 4 |
| P18 | Megpróbálom a hangom megváltoztatni, hogy másképpen csengjen. | 0 | 1 | 2 | 3 | 4 |
| F19 | Társaságban kirekesztettnek érzem magam a hangom miatt. | 0 | 1 | 2 | 3 | 4 |
| P20 | Nagy erőfeszítésembe kerül, hogy beszéljek. | 0 | 1 | 2 | 3 | 4 |
| P21 | A hangom esténként rosszabb. | 0 | 1 | 2 | 3 | 4 |
| F22 | A hangproblémáim miatt kevesebbet keresek. | 0 | 1 | 2 | 3 | 4 |
| E23 | A hangproblémám bosszant. | 0 | 1 | 2 | 3 | 4 |
| E24 | A hangom problémái miatt kevésbé jövök ki magammal. | 0 | 1 | 2 | 3 | 4 |
| E25 | A hangom miatt gátoltnak érzem magam. | 0 | 1 | 2 | 3 | 4 |
| P26 | A hangom „elhagy” beszéd közben. | 0 | 1 | 2 | 3 | 4 |
| E27 | Bosszant, ha megkérnek, hogy ismételjem meg amit mondtam. | 0 | 1 | 2 | 3 | 4 |
| E28 | Zavarba jövök, ha megkérnek, hogy ismételjem meg amit mondtam. | 0 | 1 | 2 | 3 | 4 |
| E29 | A hangom miatt úgy érzem, tehetetlen vagyok. | 0 | 1 | 2 | 3 | 4 |
| E30 | Szégyellem magam a hangom miatt. | 0 | 1 | 2 | 3 | 4 |
| | Hogyan jellemezné a hangját ma? | 0 | 1 | 2 | 3 | 4 |

0 = normális, 1 = kissé hibás, 2 = közepesen hibás, 3 = nagymértékben hibás

# I.

# A laryngealis electromyographia szerepe a hangszalag-mozgászavarok diagnosztikájában és az alkalmazott kezelés kiválasztásában

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A hangszalag-immobilitást okozó kórképek terápiás lehetőségeinek fejlődése megkövetelte a diagnosztikai módszerek párhuzamos megújulását is. Az utóbbi években ez a tendencia vezetett a már 70 éve ismert laryngealis electromyographia újrafelfedezéséhez. A nemzetközi irodalom áttekintésével és saját tapasztalataik alapján a szerzők bemutatják az eljárás alkalmazásának indikációját, technikai követelményeit és módszertanát, különös tekintettel az eredmények értékelésére. A laryngealis electromyographia lehetővé teszi a beidegzési zavarból és a mechanikus fixációból adódó hangszalag-immobilitás elkülönítését. Hangszalagbénulás esetén továbbá segítséget nyújt az idegsérülés fokának objektív megbecsülésében, a betegség prognózisának felállításában, az esetleges hangréstágító beavatkozás indikációjában és pontos típusának meghatározásában. A dinamikus rehabilitációs beavatkozások várható egyre szélesebb elterjedése sem képzelhető el az eljárás rutinszerű alkalmazása nélkül. Ezek a lehetőségek mindenképpen szükségessé teszik a laryngealis electromyographia bevezetését a gégészeti centrumokban.
Orv Hetil. 2018; 159(8): 303–311.

**Kulcsszavak:** laryngealis electromyographia, hangszalagbénulás, hangszalag-mozgászavar

## The role of laryngeal electromyography in the diagnosis of vocal cord movement disorders

The development of the therapeutic possibilities of vocal cord immobility necessitated the parallel renewal of diagnostic methods. In the last years, laryngeal electromyography, which was first introduced more than 70 years ago, has been re-discovered. After reviewing the international literature and their own experience, the authors present the indications, technical requirements, method and, particularly, the evaluation of the results of this procedure. Laryngeal electromyography makes the differentiation between mechanical fixation and immobility with neurological origin of the vocal folds possible. In case of laryngeal paralysis/paresis it also evaluates objectively the severity of neural injury, the prognosis of the disease and the necessity of any glottis-widening procedure. The widespread application of dynamic rehabilitation interventions is not conceivable without the routine application of laryngeal electromyography, so this sensitive diagnostic tool has to be introduced in all laryngological centers.

**Keywords:** laryngeal electromyography, vocal cord palsy, vocal cord immobility

Bach Á, Sztanó B, Kiss JG, Volk GF, Müller A, Pototschnig C, Rovó L. [The role of laryngeal electromyography in the diagnosis of vocal cord movement disorders]. Orv Hetil. 2018; 159(8): 303–311.

(Beérkezett: 2017. október 26; elfogadva: 2017. december 15.)

**Rövidítések**

ELS = European Laryngological Society; EMG = electromyographia; HIV = (human immundeficiency virus) emberi immunhiány-előidéző vírus; LEMG = laryngealis electromyographia; m.CAP = musculus cricoarytenoideus posterior; m.TA = musculus thyroarytenoideus; SPA = spontán patológiás aktivitás

A hangszalagok mozgászavarainak diagnosztikája mind a hazai, mind a nemzetközi viszonylatban dominálóan az endoscopos kép és az ezt kiegészítő stroboscopia alapján történik. Kellő tapasztalat birtokában ezek a szubjektív módszerek teszik lehetővé a mechanikai fixáltságból és az idegsérülésből adódó mozgászavarok differenciáldiagnosztikáját és a gégeizmok rendellenes működésének vizsgálatát (pl. spasmodicus dysphonia vagy myasthenia gravis esetén), azonban a gégeizmok paresise vagy paralysise esetén nem adnak lehetőséget a beidegzési zavarok súlyosságának megállapítására és a betegség prognózisának felállítására sem [1]. Hangszalagbénulás esetén ezek a tényezők alapjaiban határozzák meg az esetleges korrekciós műtét indikációját és típusát. A terápiás módszerek fejlődése miatt az utóbbi évtizedekben egyre fontosabbá vált egy olyan objektív diagnosztikai módszer rutinszerű bevezetése, amely választ adhat a fenti problémákra. Kézenfekvő megoldást nyújt a neuromuscularis betegségek diagnosztikájában évtizedek óta alkalmazott electromyographia gégeizmokon történő alkalmazása. Habár a laryngealis electromyographia (LEMG) több mint 70 éve ismert, a legtöbb fül-orr-gégész, illetve foniáter a mai napig nem alkalmazza a mindennapi gyakorlatban. Ez nagy valószínűséggel arra vezethető vissza, hogy az utóbbi évekig nem létezett egységes álláspont a vizsgálat elvégzésének módszeréről, az eredmények értékeléséről és a vizsgálat klinikai gyakorlatban betöltött szerepéről [2–5]. Annak érdekében, hogy az említett kérdésekben konszenzus jöjjön létre, a European Laryngological Society (ELS) neurolaryngologiai munkacsoportja célul tűzte ki, hogy meghatározzák a LEMG alkalmazásának irányvonalait. Klinikánk évek óta részt vesz a nemzetközi munkacsoport munkájában, a 2012-ben publikált európai javaslatok módosításában, értékelésében [6, 7]. A diagnosztikus eljárás módszertani alapjainak minél szélesebb körben történő megismertetése és az optimális terápia meghatározásában betöltött szerepének bemutatása kiemelt fontosságú, hiszen az utóbbi alapvetően határozza meg a betegcsoport életminőségét is.

## Módszer

### *Indikáció/kontraindikáció*

A gégeizmok beidegzési zavara, a cricoarytenoidealis ízület diszlokációja vagy ankylosisa, a glottis hegesedése vagy tumoros fixációja klinikailag hasonló tünetegyütteshez vezet [8]. A LEMG elsődleges célja a hangszalag idegsérüléséből és mechanikus fixáltságából adódó immobilitásának elkülönítése. Idegsérülés esetén a myographia továbbá segítséget nyújt a sérülés fokának megállapításában és a reinnerváció prognózisának felállításában is. A LEMG hasznos eszköz továbbá spasmodicus dysphonia vagy a hangszalag(ok) medializálásának igénye esetén is, amelynek során célunk a hangszalagba injektált anyag (pl. botulinumtoxin, hialuronsav) minél pontosabb célba juttatása [9–12].

Vázizmok vizsgálata esetén az electromyographiának abszolút kontraindikációja gyakorlatilag nincs [13]. A gége speciális helyzetéből adódóan laryngealis electromyographia végzésekor azonban különös figyelemmel kell eljárnunk, mivel instabil légút esetén LEMG-t nem végezhetünk. A rendkívül ritka, de potenciálisan fatális komplikációk miatt (főként kétoldali hangszalag-immobilitás esetén) az esetleges intubációra készen kell állni, conicotomiás szettnek elérhetőnek kell lennie. Véralvadási zavar, a célterület sebe, ödémája, ingerléses vizsgálatkor pedig a pacemaker relatív kontraindikációt jelent. A vérrel átvihető betegségek (HIV, hepatitis) a megfelelő sterilitással megelőzhetők. LEMG-t az eddigiekben kizárólag felnőtt betegeken végeztünk, de általános érzéstelenítésben speciális relaxáció nélküli anesztézia alkalmazásával lehetőség van gyermeken történő vizsgálatra is [14].

### *Technikai követelmények*

*Elektróda:* Electromyographia során az izomrostok innervációjakor létrejövő potenciálok szummálódott végeredményét regisztráljuk extracellularisan elhelyezkedő elektróda segítségével. Ezt a szummációs potenciált mozgatóegység-potenciálnak nevezzük. Regisztrálásához felszíni vagy transcutan elektródák használhatók. A diagnosztikus célból leggyakrabban végzett transcutan LEMG-hoz koncentrikus tűelektróda használata javasolt: 50 mm hosszúságú tű lehetővé teszi a gége hátsó felszínén elhelyezkedő musculus cricoarytenoideus posterior (m.CAP) elérését is a gyűrűporcon keresztül. Ehhez azonban kellően merev, legalább 0,45 mm átmérőjű elektróda szükséges. A mérések megismételhetősége és összehasonlíthatósága érdekében érdemes mindig azonos típusú elektródát használni (TECA Elite, Disposable Concentric Needle Electrodes, 37 mm × 26 G; 50 mm × 26 G; Natus Neurology Inc., Middleton, WI, USA).

*Mikrofon:* A beteg nyakára erősített mikrofonnal történő hangfelvétel a myographiás eszköz egyik csatornáján rögzíthető, ami jelentősen megkönnyíti a gégeizmok fonációval kapcsolatos myoelectronicus aktivitásának és a különböző gégeizmok agonista és antagonista működésének összehasonlítását. Emellett a hangfelvétel lehetőséget biztosít a vizsgáló valós idejű verbális megjegyzéseinek szimultán rögzítésére is.

*Termisztor, mellkasi mozgásokat mérő öv:* A be- és kilélegzett levegő hőmérséklete a beteg orra vagy tracheoto-


**1. ábra** A laryngealis electromyographia kivitelezése a musculus cricoarytenoideus posterior (a) és a musculus thyroarytenoideus (b) vizsgálatakor

e = elektróda; m = mikrofon, me = mellkasi öv; t = termisztor

miás nyílása elé helyezett termisztorral mérhető. Ezzel párhuzamosan egy piezoelektromos elven működő mellkasi öv is monitorozza a légzési mozgásokat. A két szenzor lehetővé teszi a vizsgált gégeizmok aktivitásának és a légzési fázisok időbeli összefüggésének pontos rögzítését.

*Indirekt laryngoscopia:* A gégemozgások transnasalis fiberendoscopos követése további adatokat biztosít az elvezetett izomválaszok és az általuk biztosított valós hangszalagmozgások közötti kapcsolat értékeléséhez.

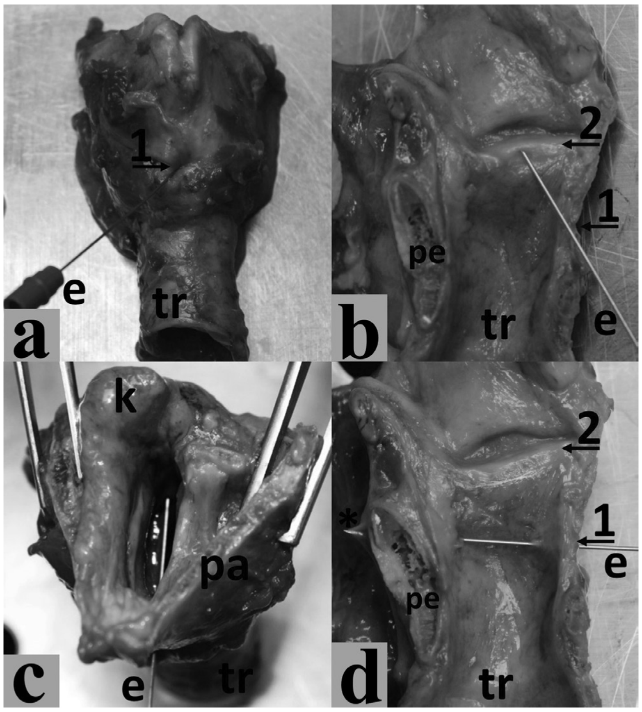
Vizsgálatainkhoz egy 12 csatornás, a gégeizmok elektromos stimulálására is alkalmas NIHON KOHDEN: Neuropack X1 (Nihon Kohden Corp., Tokyo, Japan) electromyographot használunk. Az adatokat egy speciálisan erre a célra írt, MATLAB-ban (The MathWorks Inc., Natick, MA, USA) futtatható LEMG analizáló kód és az Audacity 2.1.3 software (http://audacityteam.org/) segítségével dolgozzuk fel és értékeljük [15].

## *A vizsgálat menete*

A laryngealis electromyographia olyan invazív diagnosztikai eljárás, amely a beteg aktív együttműködését követeli meg. A vizsgálat jellegéből adódóan nem mellőzhető a megfelelő tájékoztatás és a beteg írásos beleegyezése. A myographiát a fej-nyaki régió alapos vizsgálata kell, hogy megelőzze, beleértve ebbe az indirekt laryngoscopiát és a videostroboscopiát is. Ilyen módon feltárhatók az esetleges anatómiai deformitások, korábbi műtétek okozta elváltozások, infekciók – összességében minden olyan állapot, amely megnehezítheti az elektródák bevezetését. A LEMG előtt érdemes rögzíteni a beteg hangját és légzésfunkciós paramétereit is. A vizsgálatot innervációs zavar gyanúja esetén a hangszalag-immobilitás kialakulása után leghamarabb 2 héttel javasolt elvégezni [4].

A vizsgálat alatt a beteg kényelmes ülő pozíciót vesz fel *(1/a és 1/b ábra)*. Amennyiben párhuzamosan fiberoscopiát nem végzünk, a gége nyálkahártyájának és a nyak bőrének érzéstelenítése nem feltétlenül indokolt. A szükséges szenzorok, a földelés felhelyezése és a bőr fertőtlenítése után kezdjük meg a méréseket. Javasolt a vizsgálatot a musculus thyroarytenoideus (m.TA) mérésével kezdeni. Az elektróda megfelelő pozicionálásához alapvető fontosságú a ligamentum cricothyroideum (ligamentum conicum) kitapintása. A tűt a nyak középvonalában közvetlenül a pajzsporc alsó éle alatt vezetjük be. A középvonaltól kb. 30°-ra lateralisan a tűt cranialis irányba billentve a ligamentum conicumon történő áthaladás után (a nyaki lágyrészektől és a belépési szögtől függően) kb. 15 mm-re várható a musculus thyroarytenoideus elérése *(1/b, 2/a és 2/b ábra)*. Lényeges, hogy az elektróda submucosusan érje el a hangszalag izomzatát. Hirtelen jelentkező köhögési inger és a fonációkor regisztrált myographiás sinushullámok jelzik, hogy a tűelektróda vége a légútban van. A tű pozíciójának ellenőrzése a következőképpen zajlik: a hangszalag intakt beidegzése esetén, amennyiben az elektróda a m.TA-ban van, fonációkor (a beteg „í" hangot ad) az elektromos aktivitás fokozódik. Nyeléskor szintén rövid időre fokozódik az aktivitás. Mély belégzéskor a nyugalmi aktivitás csökkenése látható.

A musculus cricoarytenoideus posterior (m.CAP) vizsgálata a gyűrűporc pecsétjének penetrálásával valósítható meg. A tűelektróda beszúrásakor itt is a legfontosabb anatómiai támpont a ligamentum conicum. Az elektróda a bőrön és a ligamentum conicumon történő áthaladása után a légútba jut. Ekkor az elektródavég szabad vibrálása miatt sinushullámokat regisztrálunk, illetve a nyálkahártya irritációja miatt köhögést tapasztalunk. A középvonaltól 5–10 mm-re lateralisan a tű lassú forgatásával és posterior irányba történő tolásával átfúrjuk a gyűrűporc lamináját, és elérjük a musculus cricoarytenoideus posteriort *(1/a, 2/c és 2/d ábra)*. Amennyiben az elektródát túl mélyen vezetjük be, az a cricopharyngealis izomzatba fog jutni. Ekkor folyamatosan erős aktivitást észlelünk, amely nyeléskor hirtelen csökken. A tű pozíciójának ellenőrzése a következőképpen zajlik: a hangszalag intakt beidegzése esetén, amennyiben a tű a m.CAP-ban van, szippantáskor az elektromos aktivitás fokozódik, nyeléskor és fonációkor az aktivitás csökken.




**2. ábra** A tűelektróda helyzete a bal oldali musculus thyroarytenoideus (a, b) és a musculus cricoarytenoideus posterior (c, d) vizsgálatakor. a: A tűelektróda a ligamentum conicumon keresztül hatol a gégébe (cadaver gége, elölnézet). b: A tűelektróda hegye a bal oldali hangszalag izomzatában látható. A tűelektróda a szemléltetés érdekében a vizsgálati protokollal ellentétben nem a nyálkahártya alatt helyezkedik el (cadaver gége, bal oldali gégefél). c: A tűelektróda a ligamentum conicumon és a gége lumenén áthaladva éri el a gyűrűporc pecsétjét (cadaver gége, felülnézet). d: A tűelektróda a gyűrűporc pecsétjének átfúrása után éri el a musculus cricoarytenoideus posteriort. A szemléltetés érdekében a tűelektróda hegye (*) az optimálisnál nagyobb mértékben penetrálja a gyűrűpor pecsétjét (cadaver gége, bal oldali gégefél)

1 = ligamentum conicum; 2 = bal oldali hangszalag; e = tűelektróda; k = bal oldali kannaporc; m = mikrofon; pa = pajzsporc; pe = a gyűrűporc pecsétje; t = termisztor; tr = trachea

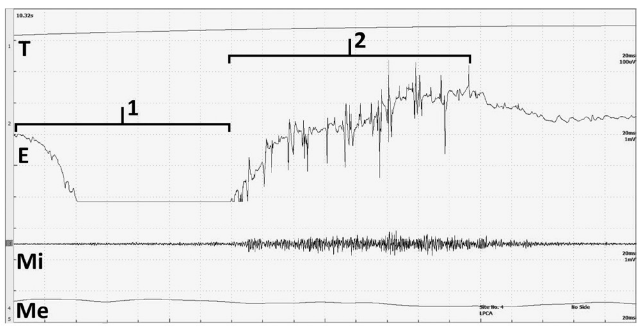
A gégeizmok agonista és antagonista aktiválódásának vizsgálata érdekében az adatokat fonáció (a beteg háromszor hosszan 'í' hangot ad), erőltetett belégzés (orron/tracheotomiás nyíláson keresztül történő gyors szippantás), nyugodt be- és kilégzés (30 s-ig történő nyugodt be- és kilégzés fonáció nélkül) alatt is vizsgáljuk. A differenciáldiagnosztikát a m.CAP elektromos stimulálásával lehet kiegészíteni. Ezt a beavatkozást jelenleg csak kutatási célból, általános érzéstelenítésben végezzük.

## *A laryngealis electromyographia értékelése*

A gégeizmok neurofiziológiai különlegességei és a technikai nehézségek miatt még jól képzett szakembernek is problémát okozhat a LEMG eredményeinek interpretálása. Éppen ezért szükséges, hogy a vizsgálat elvégzése és értékelése előre megtervezetten, standardizálva történjen. Electromyographia során a vázizmok elektromos aktivitását nyugalomban és különböző erősségű akaratlagos aktivitás esetén kell elemezni. Laryngealis electromyographia során ez igen nehéz, mivel az egyes gégeizmok akaratlagos aktivitásának mértékét nehéz szabályozni, illetve a gége izmai komplex mozgási mintázatokat követnek, és ezek a mozgások mindig több izomcsoportot involválnak [6]. Hangszalag-immobilitás esetén a különböző vizsgálómódszerek önmagukban nem bizonyító erejűek, minden beteg esetén indokolt a komplex kivizsgálás.

EMG során a mozgatóegység-potenciálok morfológiáját (alak, amplitúdó, időtartam) elemezzük. A vázizomtól eltérően a gégében egy idegrost csak kisebb izomcsoportokat innervál. Ebből adódóan a mozgatóegység-potenciálok rövidebbek és kisebb amplitúdójúak a vázizmokhoz képest. Az amplitúdó az ideg által beidegzett izomrostok számát és erősségét mutatja meg, az elektromos jel hossza pedig az ingerület sebességétől függ, amelyet az idegrost „szigetelése" befolyásol. Az izomkontrakció erejét a működő mozgatóegységek száma és ezek kisülési frekvenciája határozza meg. Az izomerő fokozásakor egyre több mozgatóegység egyre magasabb kisülési frekvenciával aktiválódik. Ezt a folyamatot recruitmentnek nevezzük. Ennek megfelelően az EMG során regisztrált jelsűrűség a növekvő izomerővel párhuzamosan aktiválódó motoros egységek számával arányos. Az ideg- és izomsérülések a normális mozgatóegység-potenciálok számának és a recruitmentnek a csökkenéséhez vezethetnek az izmok akaratlagos aktivitásakor [6].

A tűelektróda izomba történő beszúrásakor insertiós aktivitás jelentkezhet. Jellemzően ez egy sorozat erős elektromos kisülést jelent, melyek hossza nem több néhány száz milliszekundumnál *(3. ábra)*. A jelenség annak köszönhető, hogy az elektróda maga is raktároz valamennyi elektromos töltést, így az izom membránjára helyezve relatív töltéskülönbséget hoz létre. Ha az izmot körülvevő elektromos töltés nem stabil (korai idegsérülés vagy izomsérülés esetén), az insertiós aktivitás ideje meg-




**3. ábra** Insertiós aktivitás nyugodt belégzés közben a bal oldali musculus cricoarytenoideus posteriorban pajzsmirigyműtét következtében kialakult kétoldali hangszalagbénulás után 9 hónappal. A gyűrűporc penetrálásakor mért elektromos jelek (1) kívül esnek az előre beállított mérési tartományon. Az izom elérésekor normális hosszúságú insertiós aktivitás detektálható (2). Az endoscopos kép a bal oldali gégefél ab- és adductiós mozgásainak csaknem teljes regenerálódását mutatta

E = EMG; Me = mellkasi öv; Mi = mikrofon; T = termométer nyúlik. Ideg- és izomsérülések esetén az idő múlásával a normálizomszövetet zsír vagy hegszövet helyettesíti, ami az insertiós aktivitás csökkenéséhez vezet [6].

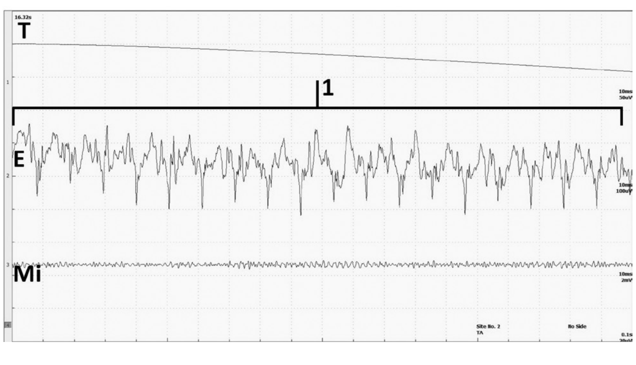
A vázizmokkal szemben, ahol nyugalomban szinte teljes elektromos csendet tudunk regisztrálni, egészséges, éber betegnél a gége teljes relaxálása csaknem lehetetlen. A nyugalmi állapotot leginkább nyugodt belégzéskor vizsgálhatjuk LEMG során. A fiziológiás háttéraktivitás így is nehézzé teszi az insertiós aktivitás megítélését. Szintén nehezebb a patológiás spontán aktivitás (SPA) detektálása. Másrészről azonban az idegsérülések csökkentik a gégeizmok háttéraktivitását. Ez a jelenség néha megkönnyítheti a vizsgálatot.

A spontán patológiás aktivitás (SPA) jeleit nyugalomban lévő izomban, mozdulatlan tűelektróda mellett kell keresnünk. Fiziológiás állapotok mellett spontán patológiás aktivitással nem találkozunk. A SPA magában foglalja a fibrillációs potenciálokat *(4. ábra)*, a megnövekedett insertiós aktivitást, a myotonicus kisüléseket, a komplex ismétlődő kisüléseket *(5. ábra)*, a fasciculatiókat és a pozitív éles hullámokat. A leggyakrabban fibrillációs potenciálokat regisztrálhatunk. Ezek alacsony amplitúdójú, rövid ideg tartó jelek, amelyek az axonok degenerációjához köthetők, és jellemzően az idegsérülést követő 10–14. napon jelennek meg. A denerváció ilyen foka csak súlyos idegsérüléskor látható, ami a regeneráció szempontjából rossz prognózist jelent. Hangsúlyozandó, hogy denerváció alatt nincs neuralis input az izomban, így abnormális hullámformák sincsenek. Ezek csak a regeneráció alatt jelennek meg [6].

Az elektrofiziológiai mérések eredményeit megfeleltethetjük a perifériás idegsérülések Seddon-féle klasszifikációjának [16]. Amennyiben single-fiber aktivitást *(6. ábra)* vagy megritkult recruitmentmintázatot *(7. ábra)* észlelünk akaratlagos aktivitás alatt, és emellett nem regisztrálunk spontán patológiás aktivitást, neurapraxiáról

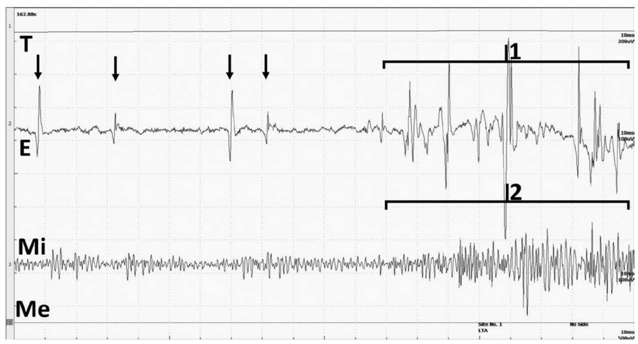

**4. ábra** Fibrillációs potenciálok a bal oldali musculus thyroarytenoideusban nyugodt belégzés közben pajzsmirigyműtét következtében kialakult kétoldali hangszalagbénulás után 9 hónappal. Az endoscopos kép a bal oldali gégefél ab- és adductiós mozgásainak csaknem teljes regenerálódását mutatta

nyíl = fibrillációs potenciál; E = EMG; Me = mellkasi öv; Mi = mikrofon; T = termométer



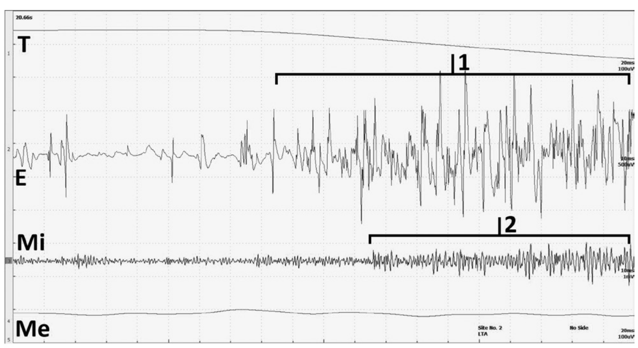

**5. ábra** Komplex ismétlődő kisülések nyugodt belégzés közben a bal oldali musculus thyroarytenoideusban pajzsmirigyműtét következtében kialakult bal oldali hangszalagbénulás után 30 hónappal. A komplex ismétlődő kisüléseket krónikus denerváció esetén regisztrálhattuk. Több izomrost egymás utáni, mindig azonos sorrendben történő kisüléséről van szó, ahol egy fibrilláló izomrost pacemakerként szerepel. Az endoscopos kép a bal oldali gégefél teljes immobilitását mutatta

1 = komplex ismétlődő kisülések; E = EMG; Mi = mikrofon; T = termométer



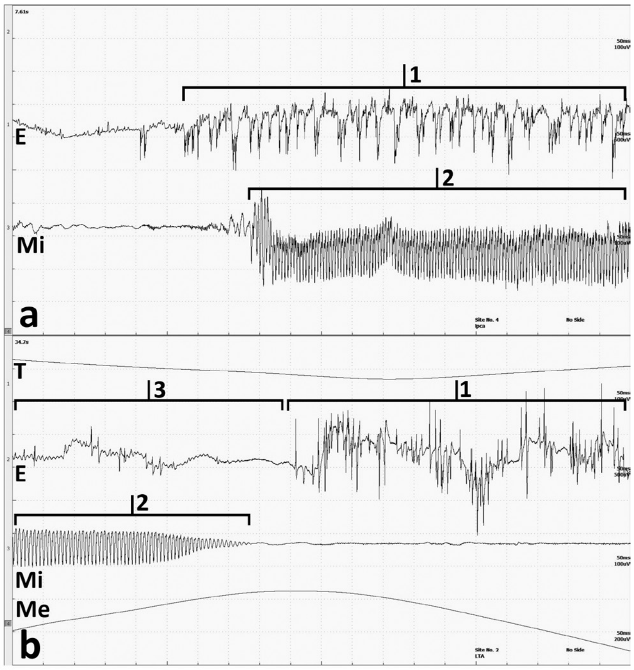

**6. ábra** Nyugalmi fibrillációs potenciálok és single-fiber aktivitás fonáció során a bal oldali musculus thyroarytenoideusban pajzsmirigyműtét következtében kialakult kétoldali hangszalagbénulás után 13 hónappal. Amennyiben LEMG során egy tűpozícióban 5 vagy annál kevesebb mozgatóegység-potenciál figyelhető meg, single-fiber aktivitásról beszélünk. Az endoscopos kép a bal oldali gégefél minimális ab- és adductiós mozgásait mutatta

Erősen csökkent akaratlagos aktivitás/single-fiber pattern (1) fonáció alatt (2); nyíl = fibrillációs potenciál, E = EMG; Me = mellkasi öv; Mi = mikrofon; T = termométer




**7. ábra** Közepes mértékben csökkent akaratlagos aktivitás fonáció során a bal oldali musculus thyroarytenoideusban pajzsmirigyműtét következtében kialakult kétoldali hangszalagbénulás után 9 hónappal. Az endoscopos kép a bal oldali gégefél csaknem normális ab- és adductiós mozgásait mutatta

Közpesen csökkent akaratlagos aktivitás (1) fonáció alatt (2); E = EMG; Me = mellkasi öv; Mi = mikrofon; T = termométer




**8. ábra** A bal oldali musculus cricoarytenoideus posterior és musculus thyroarytenoideus vizsgálata fonációkor és kilégzéskor pajzsmirigyműtét következtében kialakult bal oldali hangszalagbénulás után 25 hónappal. Az endoscopos kép a bal oldali gégefél teljes immobilitását mutatta. a: Erős synkineticus aktivitás (1) a bal oldali musculus cricoarytenoideus posteriorban fonáció (2) során. b: Synkineticus aktivitás (1) a bal oldali musculus thyroarytenoideusban belégzés során. Fonáció alatt (2) akaratlagos aktivitás nem detektálható (3)

E = EMG; Me = mellkasi öv; Mi = mikrofon; T = termométer

beszélünk, és 8–12 hét alatt a beidegzés regenerációjára számíthatunk. A regeneráció folyamán a polifázisos potenciálok száma és a mozgatóegység-potenciálok amplitúdója nő, a fibrillációs potenciálok száma csökken. Axonotmesist valószínűsít, ha idegi degenerációra utaló spontán patológiás aktivitást észlelünk. Ebben az esetben jóval kisebb az esély a beidegzés regenerációjára. Ha mégis reinnerváció következik be, az jellemzően synkinesissel (a gégeizmok együttes ab- és adductiós aktivitásával) jár [17–21] *(8. ábra)*. Neurotmesis esetén az ideg teljes keresztmetszetében károsodást szenved. Ilyen esetben reinnerváció ritkán, csak az idegvégek direkt kontaktusa esetén jöhet létre.

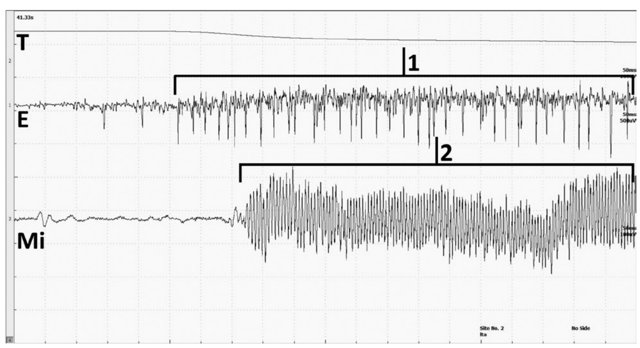
## Megbeszélés

A laryngealis electromyographiát (LEMG) 1944-ben *Weddel és mtsai* vezették be [22]. A következő évtizedekben (Faaborg-Andersen, 1956; Buchthal, 1959; Knutsson, 1969; Gay, 1972; Haglund, 1973) a módszert ugyan jelentős mértékben továbbfejlesztették [23–27], de csak az 1980-as, ’90-es években vált széles körben elterjedt diagnosztikai eszközzé. Magyarországon is voltak próbálkozások a LEMG bevezetésére, azonban a nem megfelelő technikai feltételek, a vizsgálati protokoll és a konszenzus hiánya megakadályozta a módszer széles körben történő elterjedését [28].

Amennyiben a hangszalag(ok) ab- vagy adductiós mozgásai csökkentek vagy teljesen hiányoznak, a nemzetközi irodalomban szívesebben használják a „hangszalag-immobilitás” terminust, mint a korábban használt „hangszalagbénulás” kifejezést. Habár a hangszalag-immobilitás hátterében a leggyakrabban valóban hangszalagbénulás áll, hasonló állapotot tud több, a beidegzési problémáktól független kórkép is előidézni. Az utóbbi csoportot összességében mechanikus fixációs problémáknak nevezzük. Ez utóbbi esetén, ahol a gége beidegzése intakt, általában hegesedés vagy a cricoarytenoidealis ízület ankylosisa magyarázza a csökkent mozgást. Normális hullámformák és interferenciamintázat hangszalag-immobilitás esetén mechanikus fixációt igazol *(9. ábra)* [8]. Ezzel szemben a valódi bénulásos kórképeknél jellegzetes eltéréseket regisztrálunk a LEMG során. A vizsgálatkor észlelt spontán patológiás aktivitás, a polifázisos mozgatóegység-potenciálok, a neuropathiás interferenciamintázatok idegsérülésre jellemzőek, és paresist, illetve paralysist valószínűsítenek.

A LEMG eredményéből következtethetünk a prognózisra is, mivel a patológiás spontán aktivitás hiánya és a mozgatóegység-potenciál normális/közel normális morfológiája általában jó prognózisra, valószínűsíthető reinnervációs folyamatra utal. Hasonlóan biztató jelként értékelhető a hangerő erősödésekor észlelt „recruitment spike”-ok szinkrón sűrűsödése. Gyenge prognózist jelent ezzel szemben a spontán patológiás aktivitás jelenléte, tehát akaratlagos gégemozgástól függetlenül is észlelhető, általában alacsony amplitúdójú akciós potenciálok detektálása és a csökkent vagy teljesen hiányzó recruitment [4].

A gége reinnervációja komplex és bizonytalan kimenetelű folyamat. Az alapvető probléma az, hogy a sérült idegszakaszon a regeneráció során az adduktor és abduktor rostok keverednek, és a kevert beidegzés miatt jelentősen csökken az akaratlagos mozgások hatékonysága.




**9. ábra** Normális recruitment a bal oldali musculus thyroarytenoideusban hossszan tartó intubációt követően kialakult kétoldali hangszalag-immobilitás esetén. A hangszalag-immobilitás hátterében a hátsó commissura hegesedése igazolódott

1 = normális recruitment; 2 = fonáció; E = EMG; Mi = mikrofon; T = termométer

Ez a kontraproduktív reinnerváció tehető felelőssé az enyhe fokú maradványtünetek (pl. kisfokú rekedtség, nem teljesen jól nyíló gégefél miatti, csak terheléskor jelentkező dyspnoe) mellett a gyakran súlyos, a teljes gégebénulás képét utánzó súlyos funkciózavarokért is. Az ilyen aberráns reinnervációt más néven synkineticus regenerációnak nevezzük. Mivel ezekben az esetekben többé-kevésbé mind a záró-, mind a nyitóizmokban, mind belégzés és fonáció alatt akaratlagos aktivitás mutatható ki, a LEMG önmagában képtelen elkülöníteni a funkcionális és a kontraproduktív reinnervációt [4]. Ez a magyarázata annak, hogy a hangszalagbénulás endoscopos képekkel látható végkifejlete nem mindig felel meg a LEMG során feltételezett prognózisnak. A metaanalízisek szerint tehát a LEMG nagy biztonsággal képes meghatározni a reinnerváció kedvezőtlen kimenetelét, azonban a potenciálisan kedvező LEMG-jelek ellenére a klinikailag észlelt reinnerváció nem egyértelmű a lehetséges synkineticus folyamatok kialakulása miatt [4, 8, 29–32].

A fentiek alapján a LEMG előnyei kézenfekvőek a kétoldali hangszalagbénulás optimális terápiájának meghatározásában. Amennyiben súlyos dyspnoét okozó hangszalag-immobilitás esetén a fiziológiás LEMG-lelet alátámasztja a mechanikus fixáltság fennállását, a lehetőleg funkciókímélő hangréstágító műtét elvégzése mihamarabb indokolt [33–36]. Amennyiben a vizsgálat idegi eredetű mozgászavart igazol, a klasszikus elveknek megfelelően eltérő stratégiát kell választani. Tovább árnyalja a kérdést az a tény, hogy a modern műtéti eljárások (pl. az intraoperatív idegmonitorozás) bevezetése érdemben nem csökkentette a nervus laryngeus inferior területén végzett műtétek (leggyakrabban pajzsmirigyműtét) következtében kialakuló nervus recurrens sérülések gyakoriságát. Arányaiban azonban megnőtt a reverzibilisnek tartható bénulások száma [37–39]. Emiatt sok szerző még napjainkban is minimum 6 hónapos várakozási időt javasol a definitív hangréstágító műtét előtt (akár az életminőséget jelentősen rontó ideiglenes tracheotomiával) a spontán reinnerváció lehetősége miatt [40]. A LEMG segítségével azonban már a bénulás korai szakaszában, néhány héten belül lehetőségünk nyílik azon betegek elkülönítésére, akiknél az idegsérülés súlyossága miatt nem érdemes várni a hangréstágító műtét elvégzésével. Ezekben az esetekben a munkacsoport tapasztalatától függően külső (pl. Réthi- [I–II.], King–Schobel-műtét) vagy belső feltárásból végezhető beavatkozások széles tárháza (pl. laser arytenoidectomia, posterior chordotomia) áll rendelkezésre. A jó prognózisú vagy bizonytalan esetekben a bénulás ezen szakaszában a tracheotomia helyett jó alternatív megoldás lehet olyan műtéti technikákat előnyben részesíteni, amelyek kevésbé károsítják a gégét, tehát potenciálisan reverzibilisek. Ilyen megoldás lehet a kannaporc fonállal történő endoscopos rögzítése, a klinikánkon kidolgozott endoscopos arytenoid abductiós lateropexia [41–45]. A kétoldali bénulás esetén a LEMG döntő szerepet játszhat a hangréstágító műtét oldalának meghatározásában is, hiszen ezeket a beavatkozásokat ott érdemes elvégezni, ahol a regeneráció kevésbé valószínű.

Napjainkban a gégebénulások sebészi kezelésében jelentős paradigmaváltás tapasztalható. A fenti, többségében statikus megoldásokkal szemben egyre inkább előtérbe kerülnek a dinamikus hangréstágító módszerek modern változatai. Ilyen például a reinnervációs procedúrák klinikai gyakorlatba történő rutinszerű bevezetése, melyek közül az egyik legelterjedtebb a gégeizmoknak a nervus phrenicusszal vagy a nervus hypoglossusszal történő szelektív reinnervációja. Ezek az eljárások azonban csak akkor végezhetők el sikeresen, ha a bénulás hátterében nem paralysis, hanem az idegregeneráció során a nyitó és záró beidegzés keveredéseként létrejött synkineticus aktivitás alakult ki, mivel ezekben az esetekben a folyamatos ingerlés hatására az izomatrófia elhanyagolható, és a sérüléstől általában distalisan elhelyezkedő végágak anasztomózisa képes a hatékony izommozgás kivitelezésére [42, 46]. A rendkívül bonyolult reinnervációs műtétek kiváltását jelentő, várhatóan hamarosan az ilyen típusú bénulások standard megoldásává váló „laryngeals pacing” alkalmazása során az izmok funkció-szinkrón mozgatását egy implantátumon keresztül az izomba helyezett elektródákkal érjük el. A mozgás azonban ebben az esetben is csak akkor valósítható meg, ha az elektródát izmokba belépő synkineticus regenerációt mutató idegek közelébe tudjuk behelyezni, mivel izmok direkt ingerlése nem energiahatékony [47, 48]. Ezekben az esetekben is nyilvánvaló a LEMG szerepe a megfelelő betegcsoport kiválasztásában.

## Következtetés

Összefoglalásként elmondható, hogy a LEMG a mai napig technikailag bonyolult, nagy szakmai tapasztalatot igénylő eljárás [7]. Ám az új terápiás módszerek, a gégebénulás és a regeneráció patofiziológiájának jobb megismerése, illetve az ebből fakadó modern műtéti koncepciók megjelenése és ezek közül az optimális beavatkozás kiválasztása mindenképpen szükségessé teszi a LEMG rutinszerű alkalmazását a gégészeti centrumokban.

*Anyagi támogatás:* A közlemény megírása, illetve a kapcsolódó kutatómunka anyagi támogatásban nem részesült.

*Szerzői munkamegosztás:* B. Á.: A kézirat megszövegezése, irodalmi áttekintés, az electromyographiás mérések elvégzése. Sz. B.: Lektorálás, az electromyographiás mérések elvégzése. K. J. G., G. F. V., A. M., C. P.: Szakmai tanácsadás, az electromyographiás mérések koordinálása. R. L.: Lektorálás, szakmai tanácsadás, az electromyographiás mérések koordinálása. A cikk végleges változatát valamennyi szerző elolvasta és jóváhagyta.

*Érdekeltségek:* A szerzőknek nincsenek érdekeltségeik.

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# II.

# Isolated Recovery of Adductor Muscle Function Following Bilateral Recurrent Laryngeal Nerve Injuries



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| Journal: | *The Laryngoscope* |
| Manuscript ID | lscope-18-1911.R1 |
| Wiley - Manuscript type: | Original Reports |
| Date Submitted by the Author: | 23-Oct-2018 |




| | |
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| Keywords - Combo: | Quality of Life < Laryngology, Neurolaryngology < Laryngology, Voice/dysphonia < Laryngology, Airway stenosis/reconstruction < Laryngology |
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# Isolated Recovery of Adductor Muscle Function Following Bilateral Recurrent Laryngeal Nerve Injuries

Bach et al. Isolated Recovery of Adductor Muscle Function

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The authors have no funding, financial relationships, or conflicts of interest to disclose.

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## ABSTRACT

**OBJECTIVES:** The aim of this study was to analyze the phoniatric and respiratory outcomes of a subset of bilateral vocal cord paralysis (BVCP) patients who were all treated with unilateral endoscopic arytenoid abduction lateropexy (EAAL). EAAL is a non-destructive, minimally invasive glottis widening operation, which does not damage either the surgically treated or the contralateral vocal cord. It, therefore, does not impair the regeneration potential of the recurrent laryngeal nerve.

**METHODS:** 10 out of 21 BVCP patients who were treated with EAAL showed signs of isolated adduction recovery at one year and were chosen for this study. Functional results (objective and subjective voice analysis, spirometric measurement) and vocal cord movements were assessed preoperatively, one week and one year after EAAL. Laryngeal electromyography was performed on the 12th postoperative month.

**RESULTS:** The volitional adductor movement seen on laryngoscopy was corroborated by LEMG evaluation. Peak inspiratory flow increased significantly after EAAL. Quality of Life scores also showed high patient satisfaction. Shimmer showed consistent improvement along with Harmonic to Noise Ratio, and average Maximal Phonation Time in parallel with the improving vocal cord movement. Complex voice analysis and subjective self-evaluation tests also demonstrated significant improvement.

**CONCLUSION:** EAAL, as a minimally invasive non-destructive airway widening technique, does not interfere with the potential regeneration process that can still occur after BVCP, allowing for laryngeal functional recovery. It is a safe and effective treatment for BVCP which allows a simple solution with good phonatory, swallowing and respiratory benefits, by unilateral passive and reversible vocal cord lateralization.

Level of evidence: 4



## INTRODUCTION

The treatment of bilateral vocal cord immobility is still one of the biggest challenges in Laryngology. This has been attributed the “zero-sum” balance between the need to improve breathing at the expense of sacrificed voice and swallowing functions [1]. While no debate exists about that the need for an immediate and stable airway is paramount, it is possible to achieve this while sustaining a satisfactory voice and protection from aspiration by using a minimally invasive, non-destructive and reversible glottis widening surgical technique [2]. This way the “zero-sum” game can become a “win-win”.

Theories have changed fundamentally since the Semon-Rosenbach and Wagner-Grossman hypotheses about the reason of the typical paramedian position of the vocal cord(s) after recurrent laryngeal nerve (RLN) injury [3-5]. Animal studies clearly demonstrate, that the RLN has a strong potential to regenerate after injury. It has also become evident that most patients with RLN injury attain varying levels of spontaneous recovery [6-9,10]. Partial or even total recovery of vocal cord movement can be seen in untreated patients with unilateral or even bilateral vocal cord palsy

(BVCP). Currently, the widely accepted conventional "static" glottis widening techniques are based on the partial or complete resection of the arytenoid cartilage and/or the vocal cord. Clinical signs of recovery, which are commonly in the form of vocal cord adduction, are not easily detected in patients who are treated with glottis and/or arytenoid resection procedures, although laryngeal electromyography (LEMG) can demonstrate some degree of reinnervation [4, 6]. Thus, despite the neural regeneration, vocal cord movement may not be physically possible or may be undetectable and ineffective because of the surgery performed.

By contrast, the non-destructive, minimally invasive, reversible glottis widening technique, known as the endoscopic arytenoid abduction lateropexy (EAAL), does not damage either the surgically treated or the contralateral vocal cord, and, therefore can take advantage of the regeneration of the RLN [11-16]. This way, the devastating clinical and physiological conundrum resulting from BVCP is reversed: instead of being closed, the glottis is surgically opened; but it is able to close during phonation or swallowing processes. A thorough analysis of LEMG, spirometric and acoustic tests are required to assess the comparative advantage of this surgical method compared to conventional interventions performed for BVCP.

## MATERIALS AND METHODS

### Patients

Twenty-one consecutive patients were diagnosed and treated with unilateral EAAL because of BVCP caused by thyroid surgery. Ten of the 21 (48%) patients (9 females and 1 male, mean age 54.9 years, range 34-75 years) showed endoscopic signs of only adduction recovery during the follow-up 1-year period; this homogenous group of patients with adduction only recovery without any abduction recovery was selected for this report (Table I, Fig. 1). The other 11 patients of the original 21 had unilateral (4 patients) or bilateral (2 patients) abduction recovery or failed to have any motion recovery (5 patients) during the 1-year interval indicating an entirely distinct clinical and physiological state as compared to the 10 with unilateral or bilateral adductor recovery.

In the 10 patients with isolated adductor recovery (with no abductor function detected), functional status was assessed preoperatively (as possible), one-week and one year after EAAL. Laryngeal electromyography (LEMG) of the vocal cords was performed on the 12th postoperative month to examine the neurophysiologic basis of the glottic movements. Preoperative respiratory and voice assessment was not feasible due to severe dyspnea or orotracheal intubation in 4 cases of the 10 patients. The study was approved by our Institutional Ethics Committee (registration number 47/2015). Statistical analysis (ANOVA) was performed with SigmaPlot 13 scientific graphing and statistical analysis software (Systat Software Inc, CA, USA).

**Voice Assessment**

Voice assessment was performed according to our previously published protocol and was based on the guidelines published by the Committee on Phoniatrics of the European Laryngological Society [17].

*Acoustic measurements*

Voice samples were recorded within a sound-insulated room with a high sensitivity condenser head microphone (Audio-Technica ATM 73 ac; Audio-Technica Corporation, Tokyo, Japan). The acoustic data were obtained by having three samples of a sustained /a:/ at a comfortable pitch/loudness spontaneously chosen by each patient and lasting approximately 3 seconds. The averages derived from three samples of each phonation of each patient served as the basis for the analysis. Jitter %, shimmer %, fundamental frequency (F0), harmonics to noise ratio (HNR) and maximum phonation times (MPT) were analyzed using Praat® 5.3.37 software (www.praat.org).

*Subjective self-evaluation*

To assess the patients' voices related to their quality of life, the Hungarian version of the Voice Handicap Index (VHI), was used [18]. The questionnaire contains 30 items in 3 subscales (10 items in each subscale; functional, emotional, and physical). Answers were given in a 5-point scale ranging from 0 (never) to 4 (always). The overall VHI score (raw score) can be used to grade subjective handicap from no handicap (raw score, 0–14), mild handicap (raw score, 15–28), moderate handicap (raw score, 29–50), and to severe handicap (raw score, 51–120) [19].

*Complex calculated linear index for evaluation of dysphonia*

The Dysphonia Severity Index (DSI) was used in the study to measure the overall quality of the voicing [20]. The DSI is designed to establish an objective and quantitative measurement of the perceived voice quality to assess the efficacy of therapy among dysphonic patients. The index is based on the weighted combination of objective acoustic and aerodynamic parameters, based on objective measures. DSI=(0.13xMPT)+(0.0053xHighest Frequency)–(0.26xMinimum Intensity)–(1.18xJitter %)+12.4. A normal voice >/= 5 and a severely dysphonic voice scores </= –5.

*Friedrich dysphonia index*

To evaluate the results, we also used the dysphonia index developed by Friedrich [21]. This index assesses hoarseness (G value from GRBAS scale), frequency range, dynamic range, maximum phonation time, and impairment of communication (from VHI). For each category, a score ranging from 0 (normal) to 3 (severe) is assigned. The mean value of these scores is used to grade the dysphonia.

**Respiratory assessment**

Peak inspiratory flow (PIF) is one of the characteristic and commonly used inspiratory parameters which describes the efficacy of glottis enlarging procedures [22]. Spirometric easurements were performed by using a Thor Spirotube®- PC spirometer (THOR Laboratories Kft., Székesfehérvár, Hungary). 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 [23].

**Assessment of vocal cord movement**

*Indirect endoscopy*

Vocal cord movement recovery was assessed by telescopic laryngoscopy using a 70° rigid endoscope (Karl Storz SE & Co. KG, Tuttlingen, Germany) with the aid of topical anesthesia (tetracaine) sprayed into the oropharynx. The videos were analyzed by two laryngologists. The samples were presented in a random order with respect to surgery and blinded with respect to the patient's identity. The capacity for vocal cord adduction was evaluated on each side: none: 0, minimal: 1, normal: 2, able to cross the middle line: 3.

*Laryngeal Electromyography (LEMG)*

Standard transcutaneous LEMG was performed according to the guidelines of the European Laryngological Society on the side of the larynx, in which the adduction movements were visible more definite [24, 25]. A NIHON KOHDEN Neuropack X1 EMG system (Nihon Kohden Corp., Tokyo, Japan) with concentric needle electrodes (50mm x 26G, 37mm x 26G; Teca elite, Natus Neurology, CA, USA) were used for the measurements. The data was analyzed with MATLAB R2016a (https://www.mathworks.com) and Audacity 2.1.3 software (http://audacityteam.org) by a group of three physicians specialized in laryngeal electrophysiology [26]. The thyroarytenoid (TA) and the posterior cricoarytenoid muscles (PCA) were successfully examined by LEMG in 9 and 8 patients, respectively. The following characteristics were evaluated: insertional activity (none: 0, reduced: 1, normal: 2, increased: 3); pathological spontaneous activity such as fibrillation potentials, myotonic discharges, complex repetitive discharges and fasciculations (none: 0, sparse: 1, clear: 2, strong: 3); volitional activity (none: 0, single fiber activity: 1, very reduced: 2, mildly reduced: 3, dense interference pattern: 4); synkinetic activity (none: 0, sparse: 1, clear: 2, strong: 3).

## RESULTS

### Endoscopic results

Vocal cord motion recovery is reported in Table I. During the one-year follow up, 18 vocal cords showed adduction movements. In 8 of 10 patients, the non-lateralized vocal cord showed complete or over-adduction. In patient #2 and #3 clear, though incomplete adduction was seen in the non-lateralized side. Two patients had more movement at a year in the lateralized side than in the unoperated side (patient #2 and #9). In those patients, the lateralized side crossed the midline to contact the other cord. In total, 8 of the 10 lateralized cords could visibly adduct at the end of one year.

**Laryngeal Electromyography results**

The results of LEMG are presented in Table II. Volitional motor unit action potential (MUAP) activity of the TA was observed in 8 of 9 cases (9/10 cases successfully having LEMG exams) with differing intensities during phonation; however, the interference pattern of the MAUP's was dense in only two cases. In the same muscle, MUAP's indicating synkinesis were detected in five cases [Fig. 2.a,b]; this means that there was increased electrical activity during inspiration. Nonetheless, the ordinal scale of LEMG detection and degree of movement seen on endoscopy was correlative with only one exception (patient #2).

In 7 of 8 cases, volitional (appropriate) MUAP activity was detected in the PCA (2 were not recorded because could not tolerate LEMG exam of the PCA in one case and of any muscle in a second case). A dense interference pattern was not detected in any of them. No visible abduction was seen in any of the larynges of these patients (this was an inclusion criterion). The mean degree of appropriate MUAP activity was 1.6 based on the scale. The same patients' mean MUAP for the TA muscle is 2.5 +/- 1.3. Synkinetic MUAP activity of the PCA muscle (increased electrical activity during phonation) was detected in 5/8 cases.



**Respiratory results**

All 10 patients showed objective and immediate airway improvement after unilateral EAAL. The average PIF increased significantly immediately from 1.01 to 2.04 l/sec. (change 1.03 l/sec., 201.95% of baseline; $p<0.001$). This parameter has increased later to average of 2.49 l/sec. [Fig. 3.a]. The significant improvement of quality of life scores also showed the patients' improved satisfaction with their respiratory function [Fig. 4.a]. The average score improved in the early postoperative period from 18.6 to 14.2, then further improved to 10.7 ($p < 0.001$).

## Voice results

The average fundamental frequency of the 10 patients slightly increased in the early and then more in the late postoperative period (109.77% of baseline and 114.09% of baseline respectively) [Fig 3.b]. The average MPT improvement was 1.78 sec. in the early postoperative period. It increased significantly to 7.08 sec. [Fig. 3.c] in parallel with the improving vocal cord movements. The value of shimmer showed continuous improvement and decreased to within the physiological range ($</=$ 6.84%) [Fig. 3.d]. Jitter and HNR slightly deteriorated right after surgery, but HNR increased significantly ($p<0.01$) during the regeneration phase compared to the early postoperative period. Jitter showed notable improvement as well, but this did not reach statistical significance [Fig. 3.e, f]. The complex voice analysis panels verified the improvement of the voice in general. The Friedrich and the Dysphonia Severity Index (nonsignificantly) improved immediately after EAAL, but showed further improvement with the regeneration process. Significant improvement (FDI: $p<0.001$; DSI: $p<0.01$) was found between the preoperative and late postoperative values [Fig. 4.b,c]. The Hungarian VHI demonstrated that patients subjectively also found their voices improved [Fig. 4.d]. The average score decreased significantly from 84.9 to 49.9, then to 24.8 (decrease of 59.5 in total; $p<0.001$).

## DISCUSSION

The human larynx appears designed to default to a rudimentary sphincter function from bilateral recurrent laryngeal nerve injury, with the vocal cords lying in a flaccid paramedian position while there is no airflow. This can allow for some degree of respiration and even phonation, which is commonly possible but tends to be of low volume and very low efficiency. Lower airway protection from aspiration becomes a passive process and often very limited. However, during inspiration, the Bernoulli principle explains the acceleration of the air column between the narrowing of the cords that can, by the generation of a Venturi vacuum, cause a further collapse of the glottic structures because no active abduction can be used to resist this movement. Clinically, this results in inspiratory stridor and necessitates urgent, if not emergency, surgical intervention.

The postinjury equilibrium of adduction and abduction forces from reinnervation clearly changes over time. The complexity of laryngeal innervation (e.g.: Galen's anastomosis, the "human communicating nerve") may be responsible for the residual innervation and may also explain or at least contribute significantly to reinnervation [27-29]. However, reinnervation is frequently synkinetic rather than functional, which may be based on the braided mixing of axons that serve antagonistic functions [6]. Furthermore, the significant numerical superiority of the adductor muscle fibers and axons leads to preferential reinnervation of adduction muscles and adduction during phonation as well as inhalation [8]. Variations in the position and function of the "paralyzed" vocal cords could be dependent on the degree and distribution of intrinsic laryngeal muscle reinnervation and synkinesis. Accordingly, BVCP generally does not mean a "dead" larynx. Quite to the contrary, in most cases, significant volitional adduction can be observed within weeks or months after nerve injury. Conversely, abduction is not known to be as common, occurring in about 30% of the larger cohort, from which the 10 patients for this report were chosen, while about 75% recovered adduction.

Laryngeal electromyography (LEMG) has been used for decades in the evaluation of vocal cord motion impairment. The technique was reinvented in the recent past and has become an essential tool of the patient selection for laryngeal pacing implantation [24,30]. Volitional motor unit action potentials (MUAP) activity of the thyroarytenoid muscles (TA) was detected in 18 of the 20 vocal cords (or 9 larynges within the 10 cases who tolerated LEMG) during phonation. Despite the frequency of synkinetic activity detection (in 5 of 9 cases), the phenomenon of preferential reinnervation of the adductor muscles as a functional outcome, is strongly supported by our results. The outcome of this "hybrid" pattern of reinnervation and the resultant vector between the adduction and abduction forces are the basis of an endoscopically obvious volitional adduction motion which enables phonation. The technically more challenging LEMG of the PCA was feasible in only 8 of 10 cases. Of the 8, synkinetic activity in the PCA was detected in 5 of these patients, none of whom were seen to have functional or visible abduction. Therefore, while electrical reinnervation of the PCA (which should cause abduction) could be demonstrated, it was clearly overpowered by the adduction from TA reinnervation. This emphasizes the need for endoscopic assessment to evaluate glottic function regardless of the LEMG results. This also validates the concept that reinnervation is *functionally* selective even if nervous input is going to both the PCA and adducting muscles like the TA.

In the case of BVCP, the ultimate goal is the rehabilitation of the all three laryngeal functions, respiration, deglutition and phonation. The conventional “static” glottis widening techniques such as arytenoidectomy or transverse cordotomy do not take advantage of the potential for adduction recovery [2] because they are based on partial or complete resection of the arytenoid cartilage(s) or the vocal cord(s). In the case of these interventions, dysphagia, aspiration and hypophonia are common side effects. In addition, the removal of the interarytenoid mucosa or its post-surgical atrophy, may also increase the risk of aspiration by producing gaps in the protective rim of the laryngeal inlet. Selective reinnervation procedures, or laryngeal pacing which may restore the physiological mobility of the vocal cord might be the ideal solutions for this problem [31,32]. However, nowadays these surgeries are performed only in a few centers around the globe.

We propose the strong adduction recovery potential found in the larynx post BVCP, can be used for the generation of active phonation and good airway protection, in parallel with an adequate airway. This is primarily predicated on the use of a minimally invasive glottis widening interventions that do not destroy the voice in the service of airway comfort. The EAAL displaces the entire vocal unit in a physiological manner without resection of phonatory structures and without consequential scarring. The procedure does not damage the interarytenoid region either, which is essential to safe, aspiration-free swallowing [33]. After the EAAL procedure, the vocal cords become straighter and tenser than after other, published endoscopic glottis enlarging interventions [11,12]. In addition, the EAAL technique produces a relatively small anterior angle compared to other interventions [12]. This further facilitates better phonatory closure along with improved breathing potential. There are only a few studies in the literature dealing with the voice quality after glottis widening surgical interventions. Compared to the commonly used posterior transverse laser cordotomy, EAAL gives better objective and subjective results. Jitter, shimmer, MPT, VHI, Friedrich index and the Dysphonia Severity Index improved significantly and in parallel with higher peak inspiratory flows [34,35]. The improvement in objective and subjective voice quality proves that EAAL does not interfere with the potential regeneration process either. Due to the non-destructive manner of the procedure, it also allows active (over) adduction movements on the untreated, and even on the lateralized vocal cord if adducting reinnervation occurs. This indicates that if reinnervation occurs, even the lateralized side can return to the service of improved glottic function. The inescapable conclusion is that adduction recovery can overcome the traction of the lateralization suture without the associated damage to the phonatory mechanism known to occur with more traditional approaches such as cordectomy and arytenoidectomy.

## CONCLUSIONS

Endoscopic arytenoid adduction lateropexy is an easy to perform, safe and effective solution of BVCP in the properly chosen patients. EAAL allows a simple, quasi-dynamic option with parallel phonatory and respiratory improvements. This is accomplished by virtue of generating a passively abducted vocal cord without sacrificing the functional integrity of the glottic aperture. This includes allowing for the potential benefits of active adduction recovery in the vocal cords. The long-held premise, that one or two of the primary functions of the larynx, (voice quality, swallowing safety and/or breathing) must be sacrificed to improve the other in BVCP, can now be discarded. We can return a patient to safe, comfortable breathing and a functional voice while avoiding iatrogenic aspiration.

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# TABLES

**Table I.** Data of BVCP patients with adduction recovery (1 year postoperative)

The lateralized vocal cord is marked with gray. Third column: grade of endoscopically detected adduction movement per vocal cord. 0: no adduction, 1: mild adduction, 2: complete adduction, 3: adduction beyond the middle line of the glottis. Two of the 10 patients showed more adduction in the lateralized side than the unoperated side (patients 2 and 9).

**Table II.** Results of laryngeal electromyography 1 year after recurrent laryngeal nerve injury.

m. TA: thyroarytenoid muscle; m. PCA: posterior cricoarytenoid muscles; **Insertional activity**: 0: none, 1: reduced, 2: normal, 3: increased; **Pathological spontaneous activity (PSA):** none: 0, sparse: 1, clear: 2, strong: 3; **Voluntional activity**: none: 0, single fiber activity: 1, very reduced: 2, mildly reduced: 3, dense: 4; **Synkinetic activity**: none: 0, sparse: 1, clear: 2, strong: 3).

**FIGURES**

**FIGURE 1.** Recovery of right vocal cord volitional adduction after bilateral vocal cord paralysis treated with left-sided endoscopic arytenoid abduction lateropexy (patient #6, postoperative 12th month, endoscopic view) with the ability to cross the midline.

a. wide glottis during inspiration
b. cross midline adduction of the right vocal cord

**FIGURE 2. Laryngeal electromyography of the left thyroarytenoid muscle in a 68-year-old female BVCP patient.** (patient #4; 12th postoperative month)

E: electromyography; T: thermometer; M: microphone

a) Very reduced volitional activity (1) of the thyroarytenoid muscle during phonation (2)
b) Sparse synkinetic activity (1) of the thyroarytenoid muscle during inspiration



**FIGURE 3. Objective respiratory and voice results after unilateral endoscopic arytenoid abduction lateropexy in BVCP patients with adduction regeneration.** Thin lines represent the changing of the individual values, the thick-dashed lines demonstrate the average of the values. The gray area represents the normal range of values. (1: preoperative measurement, 2: 1st postoperative week, 1st postoperative year, $*p \leq 0.05$, $**p \leq 0.01$, $****p \leq 0.001$)

a) Peak inspiratory flow (PIF, significant improvement)
b) Fundamental frequency (F0, non-significant change)
c) Maximum phonation time (MPT, significant improvement)

d) Shimmer (non-significant improvement)

e) Jitter (non-significant improvement)

f) Harmonics-to-noise ratio (HNR, significant improvement)

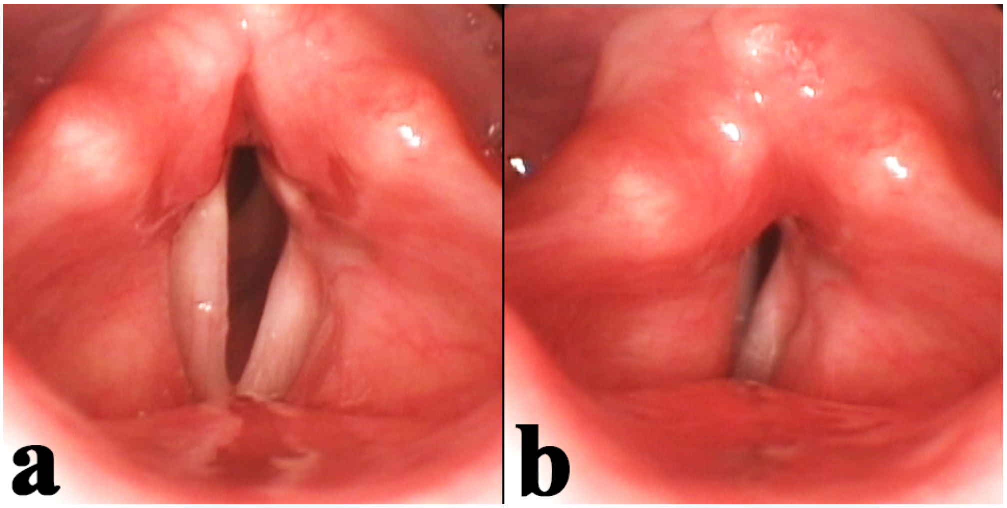
**FIGURE 4. Results of subjective respiratory and complex voice analysis panel after unilateral endoscopic arytenoid abduction lateropexy in BVCP patients with adduction regeneration.** Thin lines represent the changing of the individual values, the thick-dashed lines demonstrate the average of the values. The gray area represents the normal range of values. (1) preoperative measurement, (2) 1st postoperative week, 1st postoperative year, $*p \leq 0.05$, $**p \leq 0.01$, $****p \leq 0.001$)

a) Quality of Life score (QoL, significant improvement)

b) Friedrich dysphonia index (FDI, significant improvement)

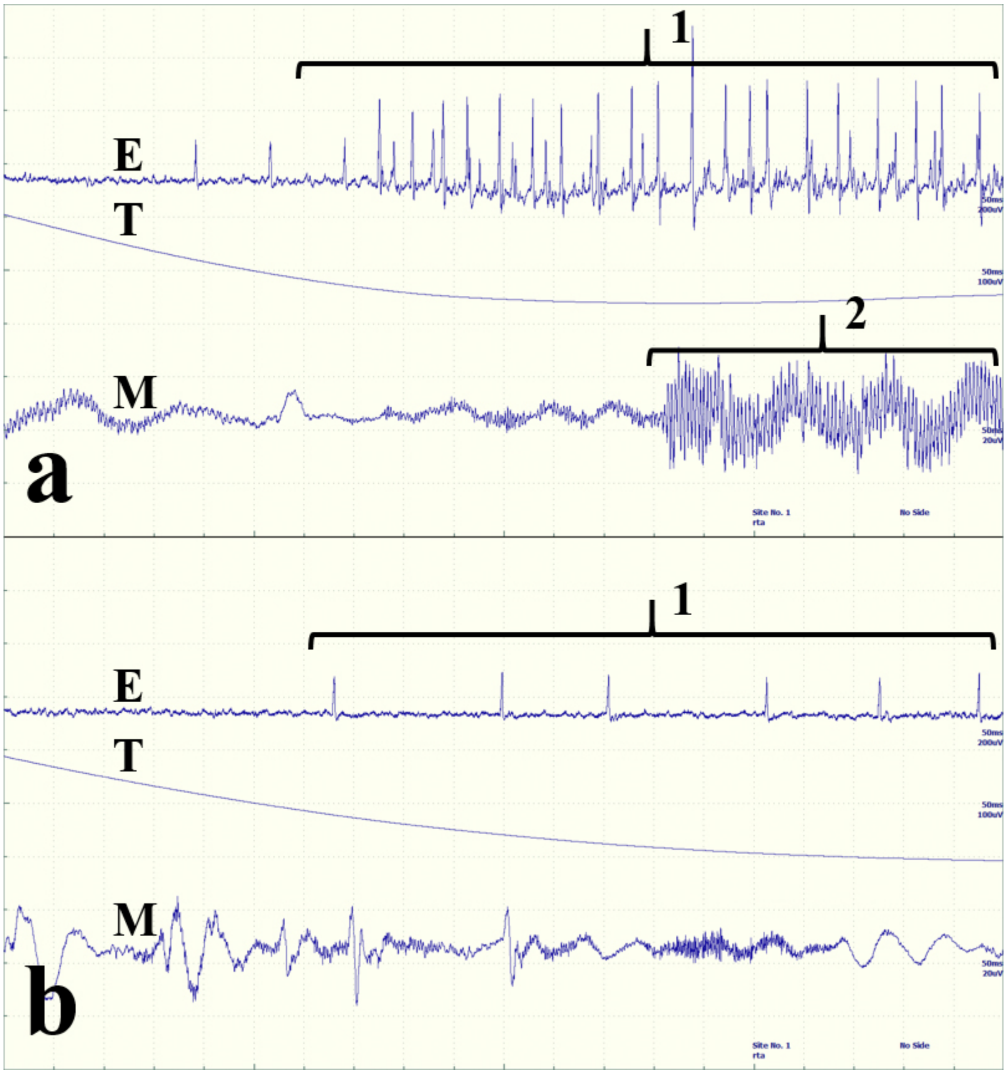
c) Dysphonia Severity Index (DSI, significant improvement)

d) Voice Handicap Index score (VHI, significant improvement)



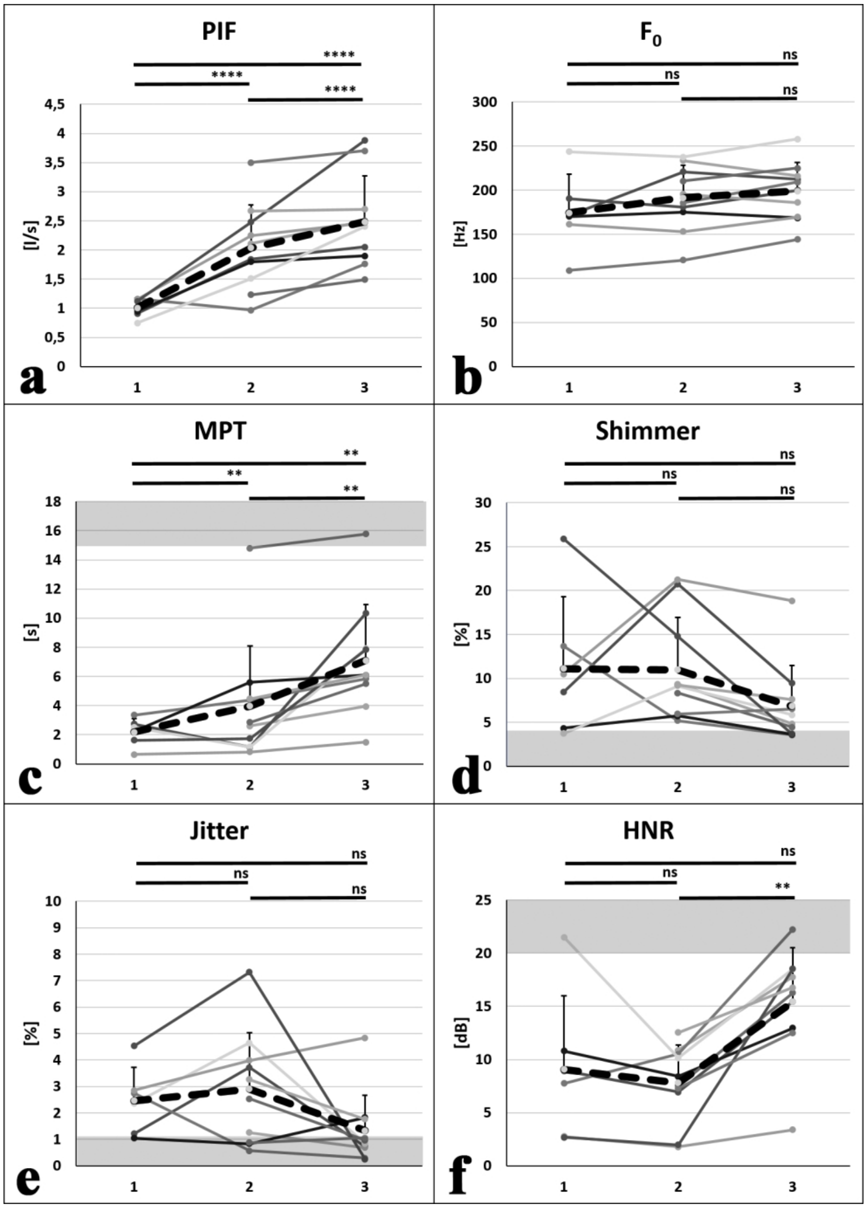

Recovery of right vocal cord volitional adduction after bilateral vocal cord paralysis treated with left-sided endoscopic arytenoid abduction lateropexy (patient #6, postoperative 12th month, endoscopic view) with the ability to cross the midline.
a. wide glottis during inspiration
b. cross midline adduction of the right vocal cord

81x40mm (300 x 300 DPI)




Laryngeal electromyography of the left thyroarytenoid muscle in a 68-year-old female BVCP patient. (patient #4; 12th postoperative month)
E: electromyography; T: thermometer; M: microphone
a) Very reduced volitional activity (1) of the thyroarytenoid muscle during phonation (2)
b) Sparse synkinetic activity (1) of the thyroarytenoid muscle during inspiration

68x72mm (300 x 300 DPI)




Objective respiratory and voice results after unilateral endoscopic arytenoid abduction lateropexy in BVCP patients with adduction regeneration.

Thin lines represent the changing of the individual values, the thick-dashed lines demonstrate the average of the values. The gray area represents the normal range of values. (1: preoperative measurement, 2: 1st postoperative week, 1st postoperative year, *p ≤ 0.05, **p ≤ 0.01, ****p ≤ 0.001)

a) Peak inspiratory flow (PIF, significant improvement)

b) Fundamental frequency (F0, non-significant change)

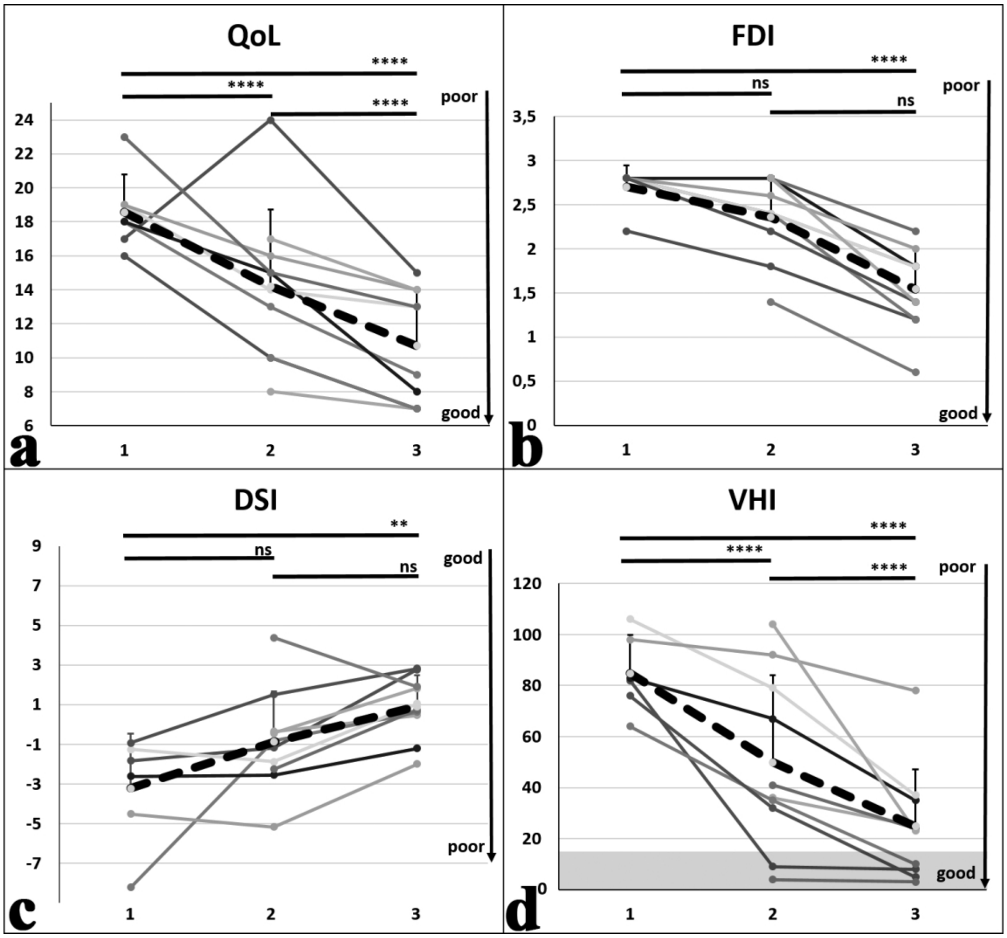
c) Maximum phonation time (MPT, significant improvement)

d) Shimmer (non-significant improvement)

e) Jitter (non-significant improvement)

f) Harmonics-to-noise ratio (HNR, significant improvement)

130x181mm (300 x 300 DPI)




Results of subjective respiratory and complex voice analysis panel after unilateral endoscopic arytenoid abduction lateropexy in BVCP patients with adduction regeneration. Thin lines represent the changing of the individual values, the thick-dashed lines demonstrate the average of the values. The gray area represents the normal range of values. (1) preoperative measurement, (2) 1st postoperative week, 1st postoperative year, $*p \le 0.05$, $**p \le 0.01$, $****p \le 0.001$)

a) Quality of Life score (QoL, significant improvement)
b) Friedrich dysphonia index (FDI, significant improvement)
c) Dysphonia Severity Index (DSI, significant improvement)
d) Voice Handicap Index score (VHI, significant improvement)

130x121mm (300 x 300 DPI)

| Patient Age/Sex | From BVCP to EAAL | Vocal fold | Adduction |
|---|---|---|---|
| #1/52/f | 2 months | Right | 2+ |
| | | Left | 1 |
| #2/46/f | 1 day | Right | 2+ |
| | | Left | 1 |
| #3/65/f | 3 days | Right | 1 |
| | | Left | 1 |
| #4/39/f | 3 months | Right | 2+ |
| | | Left | 1 |
| #5/75/m | 4 months | Right | 2+ |
| | | Left | 0 |
| #6/35/f | 1 month | Right | 2+ |
| | | Left | 1 |
| #7/68/f | 2 days | Right | 2+ |
| | | Left | 1 |
| #8/34/f | 1 month | Right | 2+ |
| | | Left | 2 |
| #9/71/f | 1 day | Right | 2 |
| | | Left | 2+ |
| #10/64/f | 2 months | Right | 2+ |
| | | Left | 0 |

| Patient Age/Sex | Vocal fold | Muscle | Insertion activity | PSA | Volitional activity | Synkinetic activity |
|---|---|---|---|---|---|---|
| #1/52/f | Right | TA muscle | 2 | 0 | 3 | 3 |
| | | PCA muscle | 1 | 0 | 0 | 0 |
| #2/46/f | Right | TA muscle | 2 | 0 | 4 | 0 |
| | | PCA muscle | 2 | 0 | 3 | 3 |
| #3/65/f | Right | TA muscle | 3 | 2 | 0 | 0 |
| | | PCA muscle | 2 | 0 | 1 | 2 |
| #4/39/f | Right | TA muscle | 2 | 0 | 4 | 3 |
| | | PCA muscle | 2 | 0 | 1 | 0 |
| #5/75/m | Right | TA muscle | Data not obtained | | | |
| | | PCA muscle | Data not obtained | | | |
| #6/35/f | Right | TA muscle | 2 | 1 | 2 | 0 |
| | | PCA muscle | 2 | 0 | 1 | 0 |
| #7/68/f | Right | TA muscle | 2 | 1 | 2 | 1 |
| | | PCA muscle | Data not obtained | | | |
| #8/34/f | Right | TA muscle | 2 | 1 | 3 | 1 |
| | | PCA muscle | 2 | 0 | 3 | 2 |
| #9/71/f | Left | TA muscle | 1 | 0 | 1 | 2 |
| | | PCA muscle | 0 | 0 | 2 | 1 |
| #10/64/f | Right | TA muscle | 2 | 0 | 3 | 0 |
| | | PCA muscle | 2 | 0 | 2 | 2 |

# III.

*The Laryngoscope*


# Rotational Thyrotracheopexy After Cricoidectomy for Low-Grade Laryngeal Chrondrosarcoma

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Ilona Szegesdi, MD; Paul F. Castellanos, MD, FCCP

**Objectives:** The complex laryngeal functions are fundamentally defined by the cricoid cartilage. Thus, lesions requiring subtotal or total resection of the cricoid cartilage commonly warrant total laryngectomy. However, from an oncological perspective, the resection of the cricoid cartilage would be an optimal solution in these cases. The poor functional results of the few reported cases of total and subtotal cricoidectomy with different reconstruction techniques confirm the need for new approaches to reconstruct the infrastructure of the larynx post cricoidectomy.

**Study Design:** Retrospective case series review.

**Methods:** Four consecutive patients with low-grade chondrosarcoma were treated by cricoidectomy with rotational thyrotracheopexy reconstruction to enable the functional creation of a complete cartilaginous ring that can substitute the functions of the cricoid cartilage. The glottic structures were stabilized with endoscopic arytenoid abduction lateropexy. Patients were evaluated with objective and subjective function tests.

**Results:** Tumor-free margins were proven; patients were successfully decannulated within 3 weeks. Voice outcomes were adequate for social conversation in all cases. Oral feeding was possible in three patients.

**Conclusion:** Total and subtotal cricoidectomy can be a surgical option to avoid total laryngectomy in cases of large chondrosarcomas destroying the cricoid cartilage. The thyrotracheopexy rotational advancement technique enables the effective reconstruction of the structural deficit of the resected cricoid cartilage in cases of total and subtotal cricoidectomy. An adequate airway for breathing, swallowing, and voice production can be reconstructed with good oncological control. In cases where the pharynx is not involved, good swallowing function can also be achieved.

**Key Words:** Airway reconstruction, chondrosarcoma, conservation resection, cricoid cartilage, cricoidectomy.

**Level of Evidence:** 4.

***Laryngoscope*, 00:000–000, 2016**

## INTRODUCTION

Chondrosarcoma of the larynx is an uncommon tumor, accounting for approximately 0.1% to 1% of all laryngeal neoplasms.[1] Its most frequent variants (95%–99% of cases) are of low- and intermediate-grade disease.[2,3] Laryngeal chondrosarcomas manifest different pathological behaviors compared to other malignancies of the larynx, and thus the treatment of these tumors is different.[4,5] Complete surgical excision with negative margins is the treatment of choice for oncological control.[6,7] The balance between radical resection and the preservation of laryngeal function is crucial. In the case of cricoid chondrosarcoma, how well this can be achieved depends on how much and what part of the cricoid cartilage remains. It is the only complete ring in the cartilage framework of the airway and is key to airway integrity. This makes preservation of function after cricoidectomy an obvious challenge.[8] The difficulty in reconstruction after the loss of the cricoid often leads to total laryngectomy.[9,10] To avoid this, many less radical procedures have been described. Nonetheless, due to the nature of these techniques, the chance of tumor recurrence increases.[11,12] In the case of more radical techniques, like hemicricoidectomy and the few reported cases of subtotal and total cricoidectomy, prolonged stenting is unavoidable. If autografts such as with rib are used, the donor site complications are not rare. Stenosis is a common risk.[13–15] The authors report a reconstruction technique useful after total and subtotal cricoidectomy for cases of large, low-grade chondrosarcomas of the cricoid cartilage. This technique provides an oncologically sound surgery using only local structures for reconstruction. Therefore, it efficiently leads to an adequate and stable airway with acceptable voice quality and swallowing function.

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Editor's Note: This Manuscript was accepted for publication May 16, 2016.

The authors have no funding, financial relationships, or conflicts of interest to disclose.

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**DOI: 10.1002/lary.26142**

## MATERIALS AND METHODS

### *Patients*

In four consecutive patients, total cricoidectomy was performed in three patients (1, 2, and 4), and subtotal cricoidectomy was performed in one patient (3). All had low-grade chondrosarcoma of the cricoid cartilage. In all cases, magnetic resonance

| TABLE I. Patient Data and Type of the Surgery. | | | | |
|---|---|---|---|---|
| | Patient 1 | Patient 2 | Patient 3 | Patient 4 |
| Age (year) | 59 | 35 | 30 | 64 |
| Gender | Male | Male | Female | Male |
| Maximum diameter of the tumor (cm) | 4.5 | 3.0 | 2.0 | 4.5 |
| Extension of the tumor | Cricoid cartilage | Cricoid cartilage | Cricoid cartilage, 1st tracheal cartilage, lower quarter of the thyroid cartilage on the left side | Cricoid cartilage, retropharyngeal space, prevertebral fascia, oesophageal introitus |
| Mobility of the vocal cords | Bilaterally slightly impaired | Normal | Normal | Bilateral complete immobility |
| Previous surgery | – | – | – | Hemicricoidectomy, right-sided arytenoidectomy, partial resection of the right thyroid lamina |
| Cricoidectomy | Total | Total | Subtotal/right part of the cricoid lamina | Total |

imaging or computed tomography (CT) imaging demonstrated a round cystic lesion of the posterior lamina of cricoid cartilage. The cortical layer of the cartilage was infiltrated by the tumor in case 1, 2, and 4. In the third case, the lesion infiltrated the first tracheal cartilage and the lower quarter of the thyroid cartilage on the ipsilateral (left) side. The maximum diameters of the tumors were 4.5, 3.0, 2.0, and 4.5 cm (cases1, 2, 3, and 4), respectively. None of the patients had cervical or mediastinal adenopathy or findings of distant metastases. Patient data is reported in Table I.

The first three patients presented with progressive dysphonia and dyspnea that had started at least 4 months prior to their diagnosis. Vocal fold mobility was normal in the second and third cases. The first case had slightly impaired mobility.

The fourth patient was tracheostomy-dependent and was referred to the authors after tumor recurrence despite multiple laryngeal surgeries and external beam radiation therapy. Hemicricoidectomy, partial resection of the right thyroid lamina, and right-sided arytenoidectomy were previously performed. The tumor recurrence was spreading into the retropharyngeal space, infiltrating the surrounding soft tissues and extending to the prevertebral fascia. Preoperative endoscopy revealed complete immobility of both vocal folds.

## Surgical Technique

All operations were performed under general anesthesia through a horizontal incision made at the level of the cricoid cartilage. The trachea was bluntly dissected from larynx to superior mediastinum, protecting the recurrent laryngeal nerves and great vessels. Isolating the tumor, the cricothyroid and cricotracheal ligaments and the inferior horns of the thyroid cartilage were transected (Figure 1.a). In the cases of total cricoidectomy (cases 1, 2, 4) the posterior and lateral cricoarytenoid muscles were sacrificed. The cricoid cartilage was dissected at the cricotracheal ligament and then completely removed together with its outer perichondrium (Figure 1.b). The pharyngeal constrictor muscle and the esophagus were carefully dissected from the cricoid and the rest of the tissue to be resected. Then a low, inferior tracheotomy was performed through a separate skin incision below the fifth tracheal cartilage. The orotracheal tube was replaced there (cases 1, 2, 3); in patient 4, it was repositioned to this distal location from the existing tracheostomy.

## Resection Variations in Specific Cases

In the first patient, the articular surface of the arytenoid cartilages had to be resected due to the massive extension of the lesion. In the third patient, the first two tracheal rings and the lower part of the thyroid cartilage were also resected below the ipsilateral vocal fold on the left side (Figure 2.a,b). In the fourth patient, a hemipharyngectomy, a partial resection of the esophageal introitus, and an expanded resection of the surrounding soft tissues were also performed.

## Laryngotracheal Anastomosis

The distal trachea was mobilized until it could be easily pulled up to the level of the thyroid cartilage. The trachea was then rotated clockwise (looking at the trachea from above) by about 90 degrees for the anastomosis (Figure 1.c) simply because it is easier for a right-handed surgeon. In case 3, where the right side of the cricoid lamina with the right arytenoid remained after the resection, the tracheal trunk was rotated counter-clockwise to complete and support the resected part of the cricoid ring. The right posterolateral edge of the proximal tracheal cartilage was sutured to the left posterior part of the thyroid cartilage with absorbable suture (0-PDS, needle: 26 mm, 1/2 circle, round-bodied, Ethicon, Somerville, NJ) (Figure 1.d, 3.a). These massive holding threads fixed the laryngotracheal anastomosis during the healing period, and the robust needle was necessary for penetration through the rigid thyroid lamina. A second suture was placed on the opposite corner of the thyroid cartilage (the right posterior corner); thus, the trachea was fixed to the thyroid lamina on both sides rotated by approximately 90 degrees. This formed a complete ring, thereby replacing the structure of the missing cricoid cartilage.

In the next step, the arytenoid and interarytenoid mucosa were separately sutured (Vicryl 2.0, Ethicon) to the posteriorly rotated side (formerly the right side) of the trachea (Figure 3.b). Then a soft stent (silicon tube filled with gauze) was placed into the airway cavity within the reconstruction to promote better healing with less cicatricial scarring of the mucosa. This also

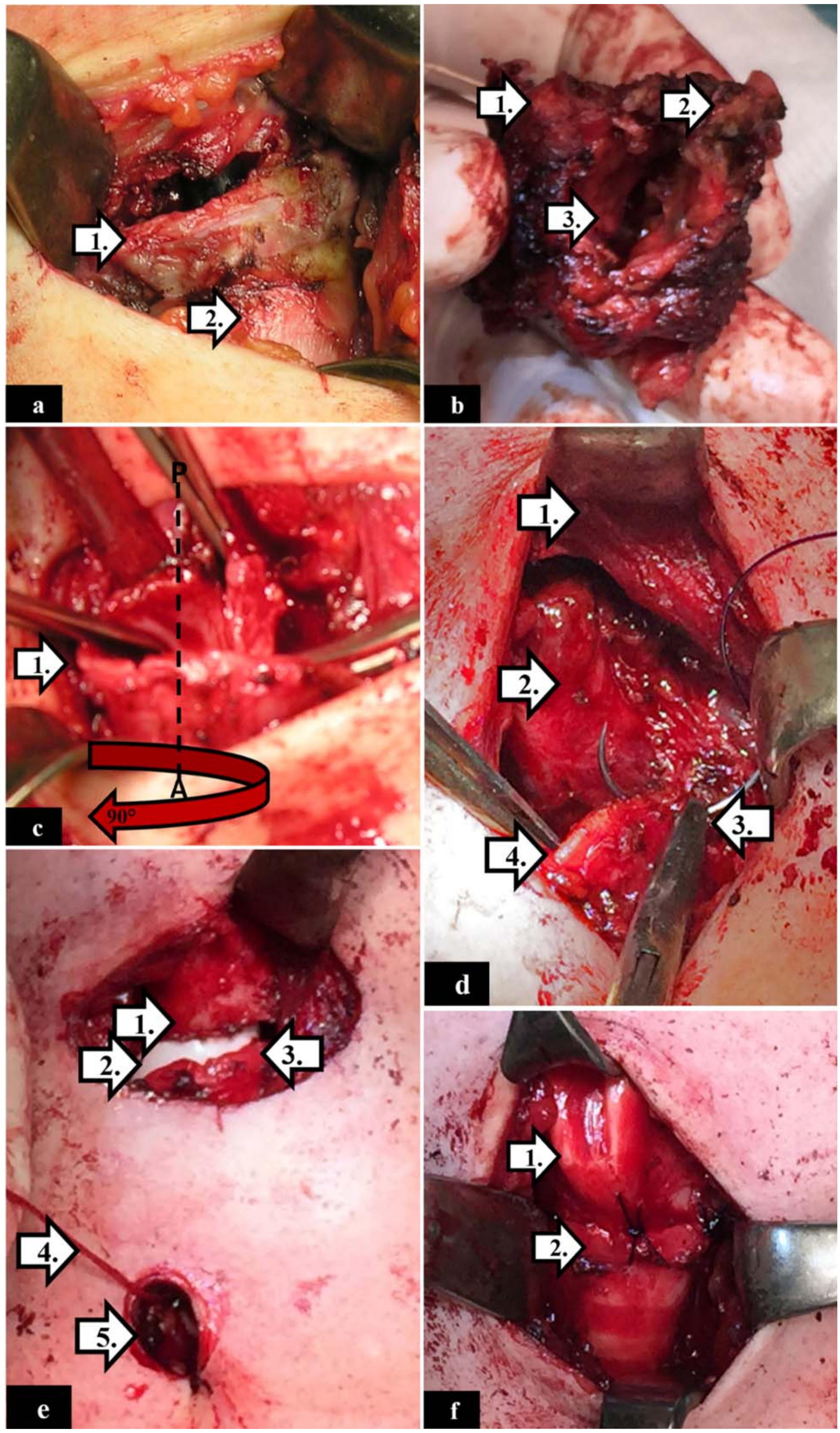



Fig. 1. (1.a) The explored cricoid cartilage (patient 2). The cricothyroid ligament is already transected. 1: the cricoid cartilage; 2: the first tracheal ring. (1.b) The completely removed cricoid cartilage (patient 2). 1,2: the articular surface of the cricoarytenoid joint; 3: the inner surface of the trachea is infiltrated by the tumor. (1.c) The rotated tracheal trunk (patient 2). 1: the trachea is rotated clockwise approximately by 90 degrees (the anteroposterior axis is marked by the dashed line). (1.d) The fixation of the rotated tracheal trunk (patient 2). 1: the thyroid cartilage is retracted; 2: the anterior wall of the esophagus; 3: the right part of the rotated trachea will be sutured to the left posterior part of the lower edge of the thyroid cartilage; 4: the posteriorly rotated midline of the trachea. (1.e) The soft stent in the reconstructed larynx (patient 2). 1: the inferior edge of the thyroid cartilage; 2: the soft stent; 3: the first rotated tracheal cartilage; 4: fixing thread of the soft stent; 5: inferior tracheostomy (the endotracheal tube is temporarily removed). (1.f) The reconstructed cartilage framework of the larynx (patient 2). 1: the remnant of the thyroid cartilage; 2: the rotated first tracheal cartilage.

served to stabilize the arytenoids in their abducted position (Figure 1.e, 2.b). The lower arch of the thyroid cartilage and the anterior (previously left) side of the trachea were sutured with four to five interrupted sutures. In summary, a modified thyrotracheopexy was performed in which the anterior wall of the subglottic part of the larynx was reconstructed with the left side of the trachea, and the posterior wall was reconstructed with the right side. The new tracheostomy was intubated with a cuffed tracheal cannula at the end of the surgery. Parenteral ceftriaxone (Ceftriaxone Kabi; Frensenius Kabi Hungary,

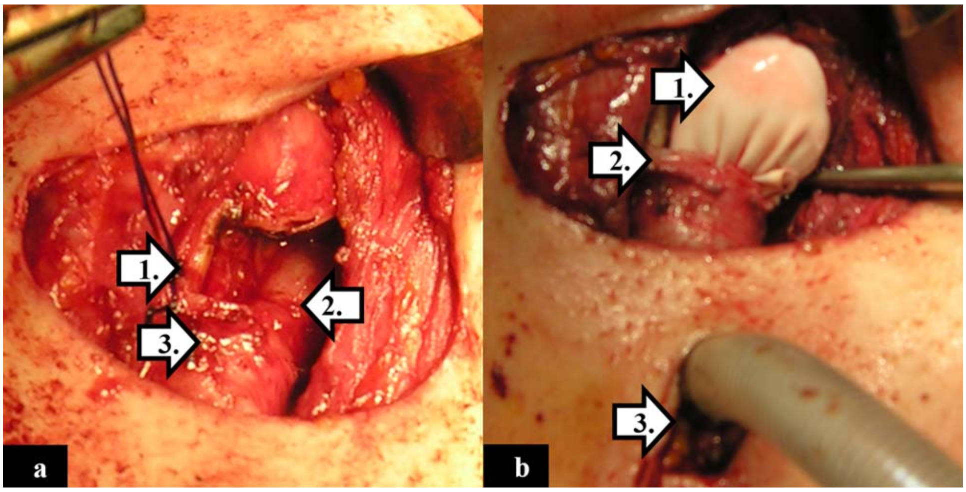



Fig. 2. Extension of the resection (patient 3). (2.a) 1: the left side of the thyroid cartilage is resected under the level of the vocal fold; 2: the left pyriform sinus; 3: the third rotated tracheal ring. (2.b) 1: soft stent; 2: the third rotated tracheal ring; 3: distal tracheostomy. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

Hungary, Budapest) and metronidazole (Klion; Richter Gedeon, Hungary, Budapest) antibiotics were administered in all cases at least for 7 days.

This procedure ensured a sufficiently wide subglottic space. However, the glottic aperture was not intrinsically assured. In cases of total cricoidectomy, the lack of the muscles attached to the arytenoid cartilages caused the prolapse of the interarytenoid mucosa and the passive adduction of the vocal folds after removing the soft stent. Therefore, a second operation was performed involving a unilateral (case 4) or bilateral (cases 1, 2) arytenoid lateropexy with a special endolaryngeal thread guide instrument (ETGI; Mega Kft, Szeged, Hungary).[16,17] In the same surgery (cases 2, 4), the edema of the supraglottic soft tissue and interarytenoid mucosa was reduced by Ultra Dream Pulse (UDP) $CO_2$ laser (DS-40U, Daeshin Enterprise, Seoul, Korea).

### *Functional Evaluation and Follow-up Care*

The voice samples were recorded with a high sensitivity (40Hz–16kHz) condenser head microphone (Audio-Technica ATM75) at a sampling frequency of 96 kHz, 24 bit (Tascam US 122MkII external soundcard) and analyzed by Praat 5.3.2.9. software (www.praat.org). The following acoustic parameters were recorded in this study: mean fundamental frequency, jitter, shimmer, harmonics-to-noise ratio, and mean phonation time. Each patient was invited to fill out the Hungarian version of Voice Handicap Index (VHI) questionnaire.[18,19] 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.[20] Paying special attention to the swallowing problems, the patients also completed the Swallowing Quality of Life questionnaire (SWAL-QOL) by McHorney.[21] Spirometric measurements were performed by using a THOR Laboratories Kft., Székesfehérvár, Hungary. Peak inspiratory flow was registered in all cases.[22,23] The status of the postoperative airway was investigated by high-resolution three-dimensional CT reconstruction. Follow-up evaluations included systematic endoscopic and radiological examinations (Figure 4.a,b and Figure 5).

## RESULTS

No major perioperative or postoperative complications occurred. Tumor-free margins were proven by histology in all cases. The laryngeal soft stents (cases 2, 3, 4) were removed during direct laryngoscopy with general anesthesia on the ninth, sixth, and 12th postoperative day, respectively. Events of the early postoperative period are shown in Table II. Endoscopic arytenoid abduction lateropexy (EAAL) was performed in cases of total cricoidectomies (cases 1, 2, 4) on the 14th, 9th, and 12th postoperative day, respectively. The edema of the false vocal folds was also reduced by Ultra Dream Pulse (DS-40U, Daeshin Enterprise) $CO_2$ laser in the same session. Edema of the supraglottic region was also reduced by laser in the third patient on the 39th postoperative day. In the second case, reopening of the closed tracheostomy was necessary for 1 day due to safety reasons 7 weeks after the surgery. Speech ability was preserved in all cases. The acoustic parameters, VHI, and QOL scores for every subject are shown in Table III. Oral feeding was allowed for the first and third patient

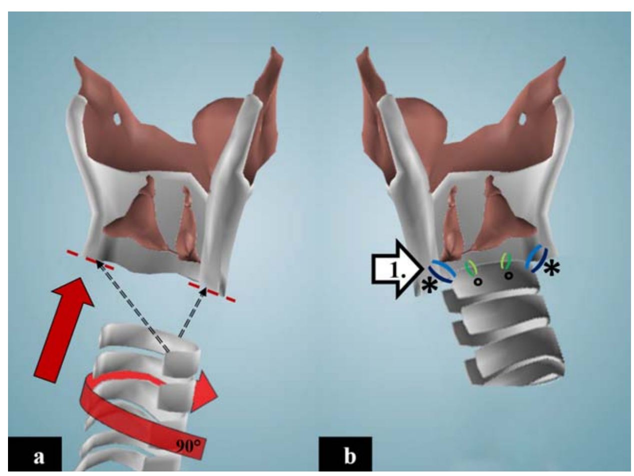
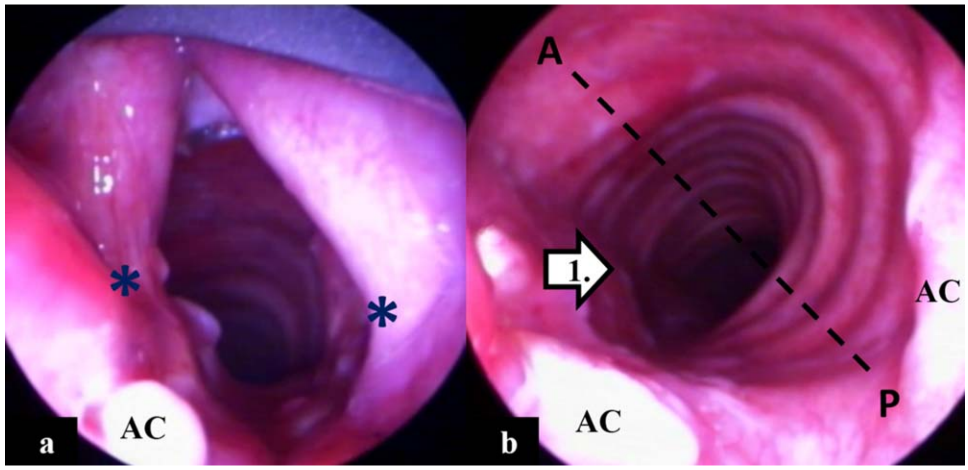



Fig. 3. Three-dimensional model of the reconstruction. (3.a) The tracheal cartilage is pulled up and is rotated clockwise approximately by 90 degrees. The inferior horns of the thyroid cartilage are resected. The dashed black lines indicate the fitting points of the reconstruction. (3.b) The posteriorly rotated right side of the trachea is sutured to the thyroid cartilage and to the arytenoid and interarytenoid mucosa. 1: the posterior suture line. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

Fig. 4. Postoperative endoscopic view (patient 1). (4.a) A properly wide glottic gap was achieved by bilateral arytenoid lateralization. *Position of the sutures of the arytenoid lateralization; AC: arytenoid cartilage. (4.b) A wide subglottic space was formed by the reconstruction. 1: the membranous wall of the trachea; (the anteroposterior axis is marked by the dashed line); AC: arytenoid cartilage. [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]




from the ninth postoperative day. Nasogastric feeding tube was used in the second patient for 20 days. The first three patients were able to tolerate a normal diet. The fourth patient, who had a partial pharyngectomy, was able to swallow saliva, but remained gastrostomy-dependent throughout the follow-up period (9 months). Functional results are reported in Table III. During the follow-up time (39, 18, 17, 9 months, respectively), the patients were free from local and distant recurrences.

## DISCUSSION

Chondrosarcoma is the most common nonepithelial neoplasm in the laryngeal region. In 75% to 80% of the cases, the lesion arises from the cricoid cartilage, with a special predilection for the paramedian inner surface of the posterior plate.[1,24] Their relatively low malignant potential allows the application of conservative surgical procedures. Options may vary from endoscopic resection and open-neck partial resection to total laryngectomy, depending on the localization, extension, and histological grade of the tumor.[25] If a complex surgery is not feasible, debulking through an anterior laryngofissure or endoscopic laser resection (generally by $CO_2$ laser) can be performed.[11] If the tumor involves less than half of the cricoid cartilage, conservative surgical treatment can be considered. Vertical hemicricoidectomy is a good surgical option with adequate oncologic and functional results as well.[14] For the reconstruction of the airway after partial cricoidectomy, several autologous graft materials have been published. Thyroid cartilage, rib cartilage, rotated epiglottic cartilage, scapular tip, and a hyoidsternohyoid osteomuscular flap can be used to reestablish the posterior wall of the larynx.[26,27] Delaere et al. published a case of a cricoid chondrosarcoma treated with a vertical hemicricoidectomy, followed by a complex two-step tracheal autotransplantation procedure.[28] However, the need for total cricoidectomy takes the problem of the airway reconstruction to a higher level. Total cricoidectomy was first described for the treatment of large chondrosarcomas by Leroux-Robert in 1956 and was recently cited by Nakano et al., Thomé et al., and de Vincentiis et al. in connection with a total of six cases.[10,29–31] The shortest stenting periods were 34, 90, and 56 days, respectively. Thomé et al. did not provide any functional results for their two cases. In the other two series (four patients), decannulation was possible in only one case.[10,31]

Because the cricoid ring is the critical structure supporting normal laryngeal function, these outcomes are not surprising. In the opinion of the authors, poor functional results from the extended resection of the cricoid can be primarily traced back to two problems. First, the reconstruction of the subglottic airway is difficult with the existing (previously described) graft options.

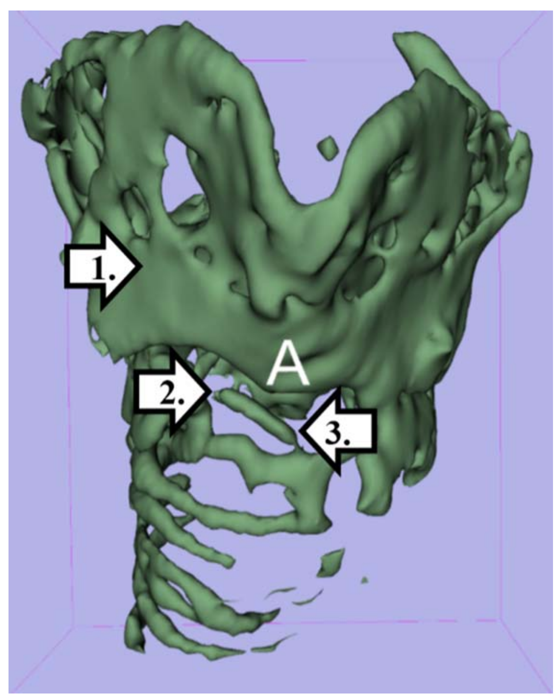



Fig. 5. Three-dimensional computed tomography reconstruction of the laryngeal framework (patient 2, 6th postoperative month). 1: the remnant of the thyroid cartilage; 2: the cricoid cartilage is resected; 3: the rotated tracheal rings (sagittal view). [Color figure can be viewed in the online issue, which is available at www.laryngoscope.com.]

TABLE II.
Postoperative Care After Total/Subtotal Cricoidectomy.

| | Patient 1 | Patient 2 | Patient 3 | Patient 4 |
|---|---|---|---|---|
| Removing of the soft stent (postoperative day) | No stenting | 9 | 6 | 12 |
| Additional intervention (postoperative day) | Bilateral EAAL | Bilateral EAAL<br>Edema reduction with UDP laser | Edema reduction with UDP laser | Unilateral EAAL<br>Edema reduction with UDP laser |
| | 14 | 9 | 39 | 12 |
| Decannulation (postoperative day) | 14 | 20 | 6 | 17 |
| Oral feeding (postoperative day) | 9 | 20 | 9 | Gastrostomy-dependent |

UDP = Ultra Dream Pulse (DS-40U, Daeshin Enterprise, Seoul, Korea); EAAL = endoscopic arytenoid abduction lateropexy.

Second, published methods do not address two issues of airway integrity: the unstable and often denervated arytenoid cartilages and the prolapse of the supraglottic soft tissues into the laryngeal cavity.

Based on this work, the subglottic support that is disrupted by the cricoidectomy can be reconstructed in a stable manner with the rotation of the autologous tracheal advancement flap. The remnant of the thyroid cartilage, together with the rotated trachea, provide a well-vascularized and mucosa-covered rigid ring. The segmental tracheoesophageal arteries must be transected on the anterior side (after rotation) down to the proximal three to four tracheal rings (where the maximal rotation happens) and maintained on the posterior side. Moreover, the transverse intercartilaginous arteries and the lateral longitudinal anastomoses remain intact and provide the basis for a quick, complication-free recovery.[32] Postthyrotracheopexy, the arytenoid cartilages, and the surrounding soft tissues are sitting atop and supported by the rotated tracheal wall. This connection, however, does not prevent the passive adduction of the vocal folds because the cricoarytenoid joints are severed and the articular surface is resected on one or both sides. There are also no attachment points for three of the four muscles that act on the arytenoid bodies. The thyroarytenoid is the only muscle that may still be functionally connected, and it only adducts the vocal fold. This can adversely affect the airway aperture. Endoscopic arytenoid abduction lateropexy can effectively address this problem because it has been already demonstrated in cases of bilateral vocal fold immobility.[16,17,33] An adequately wide glottic gap can therefore be produced with this minimally invasive procedure after total cricoidectomy.

The laryngotracheal mucosa is difficult to anastomose due to the narrow surgical access. That is why the use of the soft stent is placed within the upper airway but only for a short postoperative interval. It also helps to keep the unstable arytenoids separated, obviating the need to use a Montgomery T-tube (e.g., The Montgomery Safe-T-Tube; Boston Medical Products, MA). The effectiveness of this approach is demonstrated by the results of the respiratory function tests. Some degree of dyspnea on exertion occurred in all patients. This was especially in the only female (case 3), whose laryngeal structures were significantly smaller and whose thyroid lamina had been resected. All the other patients were able to return to premorbid activities of daily living.

Swallowing and the prevention of the aspiration are also important issues. In those patients for whom the pharyngeal structures remained intact (cases 1, 2, 3),

TABLE III.
Functional Results.

| | Patient 1 | Patient 2 | Patient 3 | Patient 4 | Physiological Values |
|---|---|---|---|---|---|
| Mean fundamental frequency (Hz) | 98,46 | 134,9 | 150,1 | 86,65 | Female: 155–334; male: 85–196 |
| Mean phonation time(s) | 4,12 | 2,39 | 3,55 | 2,91 | 10–20 |
| Jitter (%) | 7,45 | 9,36 | 9,65 | 8,05 | < 1.04 |
| Shimmer (%) | 20,86 | 19,97 | 19,47 | 15,24 | < 3.81 |
| Harmonics-to-noise ratio (dB) | 1,86 | 4,6 | 0,48 | 2,17 | 20 < |
| Voice Handicap Index | 14 | 51 | 20 | 25 | Min: 0; max: 120 |
| Peak inspiratory flow L/min) | 108 | 134,4 | 90 | 83,4 | – |
| Quality of Life | 9 | 14 | 10 | 12 | Min: 6; max: 25 |
| SWAL-QOL | 212 | 167 | 200 | Gastrostomy-dependent | Min: 44; max: 220 |
| Follow-up (month) | 38 | 17 | 16 | 8 | |

SWAL-QOL: Swallowing Quality of Life.

radiologically proven, safe swallowing could be achieved in a reasonable period of time. The results presented confirm that the mucosa of the arytenoid region can be preserved by these techniques. The protecting laryngeal reflex enables an adequate pharyngeal swallowing function despite the impairment of the glottic motions. Crumley observed this after partial medial arytenoidectomy as well.[34] For the patient who required a partial pharyngectomy (case 4), the widening of the esophageal introitus such as with a free graft or other flap technique might still be a possible option in the future to restore physiological deglutition.

A decline of voice quality was inevitable in these patients due to the resection of the arytenoid muscles (cases 1, 2, 4). Despite the whispering voice and the relatively low phonation time, a socially acceptable voice was maintained in all patients. While accounting for oncological concerns in radical surgery, it may still be possible to preserve the muscles attached to the arytenoids and the recurrent laryngeal nerve branches. This could lead to higher voice quality by the preserved motion of the vocal folds.

## CONCLUSION

Total cricoidectomy is an excellent surgical option to obviate the need for total laryngectomy in cases of large chondrosarcomas destroying the cricoid cartilage. We present an easily performed reconstruction option using local tissues that are well-vascularized, readily available, and appropriately shaped. This facilitates the creation of an adequate airway in a single- or two-stage process, and enables voice preservation and the potential for safe swallowing. Moreover, this can be achieved in accordance with the concepts of oncologically sound surgery and only a temporary tracheostomy. This technique is described for low-grade chondrosarcoma but might be a reasonable option for other types of cricoid malignancy or even high-grade subglottic stenosis.


### Acknowledgment

The authors wish to thank Dr. Kathleen I. Castellanos for reviewing the article. Her assistance is greatly appreciated.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