

**NEW ASPECTS OF CLINICAL APPLICATION OF ENDOSCOPIC ARYTENOID  
ABDUCTION LATEROPEXY**

**PhD Thesis**

**Ádám Bach M.D.**

**Department of Oto-Rhino-Laryngology, Head and Neck Surgery  
University of Szeged**

**University of Szeged,  
Clinical Medical Sciences Doctoral School**

**PhD Program:  
Clinical and Experimental Research for Reconstructive and  
Organ-sparing Surgery**

**Program director: Prof. Lajos Kemény M.D.**

**Supervisor: Prof. László Rovó M.D.**



**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 chondrosarcoma.** Laryngoscope. 2017;127:1109-1115.  
Impact factor: 2,442

**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<sub>0</sub>** 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

## 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. 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. 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. 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. 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. 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. 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. 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. Our research team joined this international LEMG group in 2013 to reintroduce this diagnostic tool in Hungary. 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. 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. 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. 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.

## **3. INTRODUCTION OF LARYNGEAL ELECTROMYOGRAPHY INTO CLINICAL PRACTICE**

### **3.1. 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.

## **3.2. Method**

### **3.2.1. Indications**

Vocal fold motion impairment is a clinically heterogeneous disorder that provides challenges in diagnosis and management at every level. 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).

### **3.2.2. Equipment**

*Electromyography electrodes:* For the transcutaneous registration of motor unit potentials concentric needle electrode are used. 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.

*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.

*Thermistor and piezoelectric thorax expansion belt:* 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.

*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 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.

### **3.2.3. EMG monitoring**

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. 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. 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.

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, force sniffing inspiration and during calm ex- and inspiration for 30 sec.

#### **3.2.4. Interpretation of LEMG**

During EMG, the morphology (shape, amplitude, duration) of the motor unit potentials is analyzed. 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.

In our protocol the following characteristics are evaluated: insertional activity, pathological spontaneous activity such as fibrillation potentials, myotonic discharges, complex repetitive discharges and fasciculations, volitional activity and synkinetic activity.

For routine clinical use, it is convenient to classify electrophysiological findings according to Seddon into neurapraxia, axonotmesis, or neurotmesis. 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. 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. 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.

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

### **4.1. Introduction**

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. 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. 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.

### **4.2. Materials and methods**

#### **4.2.1. Patients**

Ten patients were treated with unilateral EAAL because of BVCP showed endoscopic signs of only adduction recovery during the follow-up 1-year period. 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 12<sup>th</sup> 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.

#### **4.2.2. Voice Assessment**

Voice assessment was performed according to our previously published protocol and was based on the guidelines published by the Committee on Phoniatics of the European Laryngological Society. Jitter %, shimmer %, fundamental frequency (F0), harmonics to noise ratio (HNR) and maximum phonation times (MPT) were analyzed. To assess the patients' voices related to their quality of life, the Hungarian version of the Voice Handicap Index (VHI), was used. Dysphonia Severity Index (DSI) and Friedrich dysphonia index were also used for the evaluation of the functional results.

#### **4.2.3. Respiratory assessment**

Peak inspiratory flow (PIF) is one of the characteristic and commonly used inspiratory parameters which describes the efficacy of glottis enlarging procedures. 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.

#### **4.2.4. Assessment of vocal cord movement**

##### *Indirect endoscopy*

Vocal cord movement recovery was assessed by telescopic laryngoscopy using a 70° rigid endoscope. 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.

### *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. A NIHON KOHDEN Neuropack X1 EMG system with concentric needle electrodes were used for the measurements. The data was analyzed by a group of three physicians specialized in laryngeal electrophysiology according our LEMG protocol.

## **4.3. Results**

### **4.3.1. Endoscopic results**

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. Two patients had more movement at a year in the lateralized side than in the unoperated side. 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.

### **4.3.2. Laryngeal electromyography results**

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. Nonetheless, the ordinal scale of LEMG detection and degree of movement seen on endoscopy was correlative with only one exception.

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. Synkinetic MUAP activity of the PCA muscle (increased electrical activity during phonation) was detected in 5/8 cases.

#### **4.3.3. 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. This parameter has increased later to average of 2.49 l/sec. The significant improvement of quality of life scores also showed the patients' improved satisfaction with their respiratory function. The average score improved in the early postoperative period from 18.6 to 14.2, then further improved to 10.7.

#### **4.3.4. Voice results**

The average fundamental frequency of the 10 patients slightly increased in the early and then more in the late postoperative period. The average MPT improvement was 1.78 sec. in the early postoperative period. It increased significantly to 7.08 sec. in parallel with the improving vocal cord movements. The value of shimmer showed continuous improvement and decreased to within the physiological range. Jitter and HNR slightly deteriorated right after surgery, but HNR increased significantly during the regeneration phase compared to the early postoperative period. Jitter showed notable improvement as well, but this did not reach statistical significance. 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 was found between the preoperative and late postoperative values. The Hungarian VHI demonstrated that patients subjectively also found their voices improved. The average score decreased significantly from 84.9 to 49.9, then to 24.8.

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

### **5.1. Introduction**

Laryngeal chondrosarcomas manifest different pathological behaviors compared to other malignancies of the larynx, and thus the treatment of these tumors is different. 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. The difficulty in reconstruction after the loss of the cricoid often leads to total laryngectomy.

### **5.2. Materials and methods**

#### **5.2.1. Patients**

Total cricoidectomy was performed in three and subtotal cricoidectomy was performed in one patient. All had low-grade chondrosarcoma of the cricoid cartilage. The maximum diameters of the tumors were 4.5, 3.0, 2.0, and 4.5 cm respectively. None of the patients had cervical or mediastinal adenopathy or findings of distant metastases. The first three patients presented with progressive dysphonia and dyspnea that had started at least 4 months prior to their diagnosis. The fourth patient was tracheostomy-dependent and was referred to the authors after tumor recurrence despite multiple laryngeal surgeries and external beam radiation therapy.

#### **5.2.2. Surgical technique**

After the exploration of the laryngotracheal complex, the cricothyroid and cricotracheal ligaments and the inferior horns of the thyroid cartilage were transected. In the cases of total

cricoidectomy 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. 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. 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. 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.

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 or bilateral arytenoid lateropexy with a special endolaryngeal thread guide instrument. In the same surgery, the edema of the supraglottic soft tissue and interarytenoid mucosa was reduced by Ultra Dream Pulse (UDP) CO<sub>2</sub> laser.

### **5.2.3. Functional evaluation and follow-up care**

Voice assessment and spirometric measurements were performed according to our previously published protocol and was based on the guidelines published by the Committee on Phoniatics of the European Laryngological Society. Paying special attention to the swallowing problems, the patients also completed the Swallowing Quality of Life questionnaire (SWAL-QOL) by McHorney. The status of the postoperative airway was investigated by high-resolution three-dimensional CT reconstruction. Follow-up evaluations included systematic endoscopic and radiological examinations.

### **5.3. 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 9<sup>th</sup>, 6<sup>th</sup>, and 12<sup>th</sup> postoperative day, respectively. Endoscopic arytenoid lateropexy was performed in cases of total cricoidectomies (patient #1,2,4) on the 14<sup>th</sup>, 9<sup>th</sup>, and 12<sup>th</sup> postoperative day, respectively. The edema of the false vocal folds was also reduced by UDP CO<sub>2</sub> laser in the same session. Edema of the supraglottic region was also reduced by laser in the third patient on the 39<sup>th</sup> 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. Oral feeding was allowed for the first and third patient from the 9<sup>th</sup> 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.

## **6. DISCUSSION**

### **6.1. 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 unite 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.

The reinnervation of the laryngeal muscles is a complex and precarious process. 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.

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. If the test proves vocal fold immobility with neurological origin, different strategy should be chosen in accordance with the classical principles. Even nowadays, many authors suggest a minimum of 6 months waiting period before the definitive glottis widening surgery due to the possible spontaneous reinvention. 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.

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

The postinjury equilibrium of adduction and abduction forces from reinnervation clearly changes over time after recurrent laryngeal nerve injury. The complexity of laryngeal innervation may be responsible for the residual innervation and may also explain or at least contribute significantly to reinnervation. 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.

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. After the EAAL procedure, the vocal cords become straighter and tenser than after other, published endoscopic glottis enlarging interventions. In addition, the EAAL technique produces a relatively small anterior angle compared to other interventions. This further facilitates better phonatory closure along with improved breathing potential. 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.

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

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. 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. An adequately wide glottic gap can therefore be produced with this minimally invasive procedure after total cricoidectomy.

## **7. CONCLUSIONS AND NEW RESULTS**

### **7.1. 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.

### **7.2. 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.

### **7.3. 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 in case of missing cricoid cartilage. It enables voice preservation and the potential for safe swallowing as well.

## **8. 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 gratitude also go towards my family, wife and friends whose continuous support, encouragement, belief and patience filled me with energy and making everything worthwhile.