COMPLEX VOICE MEASUREMENT PANEL FOR THE ASSESSMENT OF THE FUNCTIONAL EVALUATION OF THE LARYNGEAL SURGICAL INTERVENTIONS

Ph.D. Thesis

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2010

PUBLICATIONS related to the the PhD Thesis

- **I.** Rovó L, **Smehák G**, Tóth L, Szamosközi A, Tóth F, Kiss JG, Czigner J, Jóri J
  A kétoldali hangszalagbénulás „korai” szakában végzett hangréstágító műtét következtében létrejövő elváltozások reverzibilitásának vizsgálata laryngostroboszkópiával és objektív hangelemzéssel
  [Laryngostroboscopy and objective acustic analysis for evaluation of the reversibility of disorders developing during the „early” phase of bilateral vocal cord palsy caused by „simple” suture glottis widening technique]
  Fül-, Orr-, Gégegyógy 2005;51:85-92

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  Perineurioma originating from the recurrent laryngeal nerve, and the phonochirurgical treatment of the developed vocal fold palsy
  Eur Arch Otorhinolaryngol. 2008;265:237-41
  Impact factor 0.82

- **III.** Ungvári K, Barrak S, **Smehák G**, Szamosközi A, Rovó L, Radnai M
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  Laryngoscope 2010;120:2002-2007
  Impact factor 2.018

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Eur Arch Otorhinolaryngol (2007) (Suppl 1) 264:S48 HL112
Impact factor 0.648

III. Rovó L, Madani S, **Smehák G**, Czigner J, Jóri J
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Impact factor 0.648

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EUFOS 2007 6th European Congress of Oto-Rhino-Laryngology Head and Neck Surgery June 30th – July 4Th 2007 Vienna/Austria
Eur Arch Otorhinolaryngol (2007) (Suppl 1) 264:S101 HP 100
Impact factor 0.648

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Bally’s/Paris Hotel and Convention Center, Las Vegas, Nevada

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ABBREVIATIONS

AL:	**Aytenoid lateropexy**
B:	**Breathiness**
BVCP:	**Bilateral vocal cord palsy**
BVCI:	**Bilateral vocal cord immobility**
CAJ:	**Cicoarytenoid joint**
Clo:	**Closing (during videostroboscopy)**
CTM:	**cricothyroid muscle**
DR:	**Dynamic range**
DSI:	**Dysphonia Severity Index**
EAL:	**Endoscopic Aritenoid Lateropexy**
ETGI:	**Endolaryngeal Thread Guide Instrument**
FDI:	**Friedrich’s Dysphonia Index**
FR:	**Frequency range in Semitones**
F0:	**fundamental frequency (Pitch)**
G:	**Grade**
HNR:	**Harmonic-to-Noise ratio**
IAM:	**interarytenoid muscles**
Jitt%:	**Jitter%**
LCAM:	**lateral cricoarytenoid muscle**
LMG:	**laryngomyography**
MF:	**Mechanical fixation**
MPT:	**maximum phonation time**
MRI:	**magnetic resonance imaging**
MVI:	**maximum voice intensity**
MW:	**Mucosal Wave (during videostroboscopy)**
PCAM:	**posterior cricoarytenoid muscle**
PGS:	**Posterior Glottic Stenosis**
R:	**Roughness**

Reg:	**Regularity (during videostroboscopy)**
RLN:	**recurrent laryngeal nerve**
Shim%:	**Shimmer%**
SLN:	**superior laryngeal nerve**
Sym:	**Symmetry (during videostroboscopy)**
TAM:	**thyroarytenoid muscle**
VCI:	**vocal cord immobility**
VHI:	**Voice Handicap Index**

CONTENT

1. INTRODUCTION

1.1. The human speech in the communication

The human speech is the most important way of human communication even nowadays in our computerized world. The good voicing enables normal communication expressing our thoughts with the required tone, rhythm of the speech and builds connections, exhibits emotions as well. The improvement of the health care led to increased expectations in the treatment of speech disorders which requires more and more sophisticated speech evaluation techniques after laryngological interventions.

1.2. Problems with the voice evaluation

The physiological background of the voicing seems to have a simple mechanism. The elevated subglottal pressure produces a periodical oscillation of the true vocal cords. In reality this process is very complex, because the oscillation of the vocal cords and its mucosa is not limited to the horizontal plane but in three dimensional space as it can be measured with the modern stroboscopic and high speed videolaryngoscopy records. The anatomical background of this special 3D mucosal movement is the special lamellar structure of vocal cord surface described by Remenár and Élő [1] and by Hirano[2]. This movement is very complex, in case of hoarseness the movements became aperiodical or chaotical, although it can be described mathematically by a multivariable equation. With linear approximation, it is almost impossible to evaluate the movements' quality.

A simple subjective or semi quantitative linear scale would be a useful tool, but the evaluations which seem to be simple by the human brain are sometimes not properly performed by computers. It is the same problems as in the web-sites used small graphics called CAPTCHA. (Figure 1) The humans can easily recognize them, but the computers (robots) even using special programs are not suitable for this challenge. This is the case in voice analysis because the subjective assessment and the objective measurement mean a different approach of the same entity.

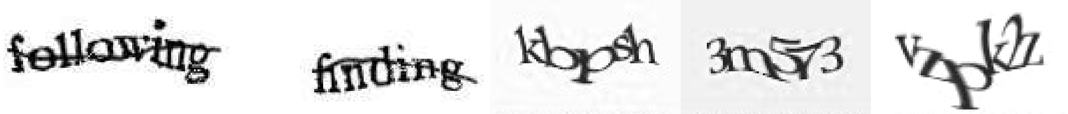

Figure 1: Samples for different CAPTCHA

1.3. The role of voice evaluation in otolaryngology

Instead of using subjective methods to describe phonation with modalities like breathy, rough etc. [3-5], it is important to introduce standardized diagnostic and therapeutic methods that describe voice quality with numeric values [6-9]. This objective evaluation is well known in other professions, and as also in other parts of the otolaryngology (e.g. audiology), in order to improve the quality of patient care. For example in otology pure tone audiometry, speech understanding quality of life questionnaire is a must, even is cases of hearing aid fitting that is not an intervention in conventional meaning. More and more calculations take into account the patient's own opinion on the state of their voice [10-12].

Unfortunately in Hungary only few phoniatric centers use the above mentioned objective methods in the diagnostic field. This problem is not related to the lack of the qualified phoniatricians, speech therapists nor the lack of the instrumentation, but the complexity of the examinations. To understand the problem of the limits of human voice evaluation performed by the otolaryngologists we should be aware about the complexity of these procedures.[13-18]

One of the leading symptoms in phoniatric disorders is the change of the timbre and the appearance of hoarseness. Since hoarseness is subjective and hard to define, the goal is to introduce a quick, short, simple, easy-to-follow numeric scale that may be used to categorize hoarseness [10] instead of a long description.

1.4. New methods in the clinical practice for evaluating the efficacy of different treatments

In the last century the introduction of analogue instruments using graphic imaginary of the human voice spectrum was a breakthrough in the phoniatric assesment compared to the subjective evaluation (good or hoarse were used previously). In these spectograms one could already identify the base frequency, the formants, and even the noise components, but these evaluations were not always reproducible. With the development of the digital technology, and the computer sciences the availability of new methods increased, and digital recording enabled the long term storage of the voice samples with an easy procedure. Despite the technical development, the description of the voice is a complicated and complex problem and the evaluations used nowadays solve only partially this problem. The development of different voice analysis softwares made the objective measurements possible. On the other hand in the last decade big centers made consensus reports about the subjective evaluation of the voice in the international literature. In 2001 the Phoniatrical Section of the European Laryngological Society announced a protocol for the validation of the phonosurgical treatments.[19] They summarized the subjective and objective examinations as well.

This numeric scales measuring the voice quality from different aspects may simplify the comparison of the results of different groups used in different treatment modalities based on various concepts. [13, 15] This protocol would standardize the phoniatric evaluations. Sometimes it is difficult to find the right balance between the conservative, and operative treatment in phoniatry. The workgroups in many cases choose the treatment followed their personal training, or routine, and their technical/instrumental possibilities. The comparable post treatment results would simplify our decision between the treatment modalities. With a simple protocol using subjective and objective evaluation can lead to unified validation of the results. We would show our examinations in two groups of patients. These groups are patients with bilateral vocal cord palsy, and patients with posterior glottic stenosis.

1.5. Historical background of bilateral vocal cord immobility, etiology, treatment options

Despite the advanced operative techniques, bilateral recurrent laryngeal nerve (RLN) injury is a serious complication of thyroid surgery even in this day and age [20]. The dyspnea caused by the developed bilateral vocal cord paralysis (BVCP) depends mainly on the position of the vocal cords and on the cardiopulmonary reserve of the patient. Life threatening conditions unequivocally require surgical intervention to prevent acute asphyxiation, however, even moderate dyspnea may restrict the patient's daily activities and thus still requires the restoration of the airway patency also via surgery [21]. In this context tracheotomy had been the gold standard procedure for centuries, but with severe possible somatic and psychological side effects. Continuous development of the anesthesia and the improvement of diagnostic and surgical instruments in the last decades allowed this inconvenient state to be avoided. The most types of surgical interventions generally include the resection of the glottic structures (complete or partial vocal cord resection, and/or arytenoidectomy [22-24]), but as their phoniatric assessment has been revealed even a diminished resection may lead to a significant voice impairment [21, 25, 26]. Their indication is therefore commonly considered when permanent paralysis is confirmed by laryngomyography [27] .

Another concept has arisen from the end of the last century, which is the idea of displacing the vocal cord structures without tissue resection, [28-32] in order to assure a reversible glottis enlarging procedure [23]. The main group of these endoscopic procedures, however, is based on the concept of simple suture vocal cord lateralization, in which the externally [32] or endo-extralaryngealy inserted [33] suture loop ensures the airway improvement. One of the best known among them is the Lichtenberger's method.[34, 35] These techniques may not be only reversible [31, 32, 36], but they may provide the permanent airway restoration for BVCP as well [31, 36, 37]. This data outlines a more simple management of BVCP, nevertheless, according to recent judgment of most laryngologists the role of these techniques has yet to be defined. A possible explanation for this incertitude is that phoniatric studies have not supported the advantage of these procedures compared to other techniques.

1.6. Physiological theories for the explanation of the regeneration of injured recurrent laryngeal nerve; their influence on the treatment options and the postoperative results

Throughout the history of laryngology, investigations have studied and compiled theories about the vocal cord in cases of paralysis. These studies are dealing with the fold position, functional deficit and prognosis of recovery. According to Semon [38] (1881) (Semon-Rosenbach law) the only adductor centers have mutual cooperation and anatomical connections effectively protect the adductor muscles against disease producing influences. He suggested that the abductors are more “automatic” and therefore they have less resistance against disease-producing causes. Jackson and Jackson [39] (1937) agreed with the above opinion, and stated that with any lesion of the recurrent laryngeal nerve (RLN) the abductor muscles are affected first, then the tensors second, and the adductors last. These widely cited studies might have been the basis of considering the paralytic paramedian vocal cord position as a “posticus” paralysis. The Wagner-Grossman hypothesis (cit:[40]) was developed to explain the vocal cord phenomena related to the paralysis because Semon’s explanation lacked substantiation. This theory explained the paramedian or intermedier position of the vocal cord on the basis of the ipsilateral cricothyroid muscle (CTM) activity, therefore the effect of external motoric branch of the superior laryngeal nerve (SLN). Since the work of Faaborg-Anderson [41], in 1957, on the normal electrophysiology of the larynx, many laryngologists have concentrated on diagnosing by laryngomyography (LMG). Dedo [40] reconfirmed the Wagner-Grossman hypothesis in 1970 on 52 patients by electromyography. Conversely, many other authors debated this theory. Hirano at al [42], in a study of 114 patients with vocal cord paralysis based on RLN injury or RLN plus SLN paralysis (vagal paralysis) found that the vocal cords remained paramedian rather then intermediate, as suggested by the Wagner-Crossman hypothesis. Tanaka et al [43] also noted that the CTM activity had little effect on the vocal cord bowing, which was clinically considered to be a vagal lesion, but markedly reduced thyroarytenoid muscle (TAM) activity can be found in 69% of these cases by LMG. Woodson [44] reported on 14 cases of unilateral vocal cord paralysis (7 vagal and 7 RLN) and noted no difference in the position of the vocal cords. Koufman et al. [45] also analyzed the vocal fold position in a number of different disorders, and they reached the same conclusion. According to these more-or-less contrary results, the paralysed vocal cord position (intermedier, or paramedian; the lack or presence of bowing) does not determine unambiguously the level of the neural lesion, nevertheless, some degree of worsening of the voice quality, especially in case of professional singers, is a well-known phenomenon after the injury of the external branch of the SLN after thyroid surgery. In some of our cases we also found extremely bowed paralyzed vocal cords in intermedier position after thyroid surgery, but the simultaneous external branch injury could not be excluded clearly in these cases either. The study of this question revealed new hypothesizes in the last decades. According to Crumley [46] in the acute phase of denervation the voice is breathy and hoarse and often diplophonic, and patients suffer from some aspiration (especially in case of vagal lesion) during drinking. Three or four weeks later the aspiration disappears and improvement can usually be detected in voice quality. This change may be related to the improvement in electrical activity. Hirano et al. [42] tried to determine the prognosis of the paralysis by the electrical activity of the paralyzed vocal cord. The onset of this activity before 6 months from the time of the injury was favorable for recovery. They felt that, the presence of this after six months was from synkinetic activity. Synkinesis (first described in 1982) is defined as the unintentional movement accompanying a volitional movement. This synchronous muscle contraction that usually has independent neural stimulation is thought to be related to misdirected and inappropriate reinnervation of muscles. This would lead to simultaneous isometric contraction of antagonistic muscles. This may explain the lack of the TAM atrophy and the “spontaneous” improvement of voice quality in the later phase of unilateral vocal cord paralysis in some of our cases, who did not require surgical intervention. Laryngeal synkinesis continues to play an important diagnostic and therapeutic role following recurrent laryngeal nerve (RLN) injury. Vocal fold motion impairment (formerly called "vocal cord paralysis"), hyperadducted and hyperabducted vocal folds, and certain laryngeal spasmodic and tremor disorders are often best explained by synkinesis. A closer look at these mechanisms confirms that following RLN injury, immobile vocal folds may be nearly normally functional (favorable), or spastic, hyperadducted, or hyperabducted (unfavorable). This has resulted in a functional classification of laryngeal synkinesis as follows: type I laryngeal synkinesis, with satisfactory voice and airway (vocal fold poorly mobile, or immobile); type II synkinesis, with spasmodic vocal folds and an unsatisfactory voice and/or airway; type III synkinesis, with hyperadducted vocal folds and airway compromise; and type IV synkinesis, with hyperabducted vocal folds, poor voice, and possible aspiration. This classification facilitates the understanding of laryngeal pathophysiology following RLN injuries and promotes a more scientific basis for management. [47]

Benninger et al [48], in 1994, described the position of the arytenoids as related to the relative balance of muscle contraction that controls the arytenoid position. The injury of the lateral cricoarytenoid innervation can result in the falling of the arytenoid medially into the supraglottic inlet. Posterior cricoarytenoid muscle (PCAM) loss decreases lateral sliding and abduction, and TAM loss causes atrophy of the vocal cord with bowing due to loss of muscle mass, and lack of anterior pull of the vocal process. Woodson's [49] animal studies also demonstrated that variability in the vocal fold position was due to random reinnervation.

Crumley and McCabe [50], in 1982, in an animal experiment found that the reinnervation after the transsection of the recurrent laryngeal nerve was unpredictable and random. The branch of the RLN to the PCAM (abductor fibers) is mostly slow-twitch fibers, whereas the fibers to the TAM and lateral cricoarytenoid muscle (LCAM) are mostly fast-twitch. Slow-twitch fibers have been shown to reinnervate many more muscle fibers than fast-twitch fibers.

Nomoto et al. [51] in a study of denervated feline laryngeal muscles found nerve terminals, resembling autonomic nerves, reinnervating the neuromuscular junctions. Depending on the nature of the injury, the reinnervation could come from nerves adjacent to the RLN. According to him, fibers can come from the ansa cervicalis nerves or from other nerve supplies, but probably the clinical importance of this "external reinnervation" is not significant.

A more interesting and returning question for centuries in the literature is the role of SLN in the innervation of the intrinsic muscle of the larynx. Beside the well-known motoric innervation of the CTM by its external branches, authors supposed some kind of motoric activity of its internal one. Réthi [52] in 1955, analyzed the paralyzed vocal cord position in human larynx on a theoretical basis. He has already described that the paramedian position is the consequence of the "tonic" activity of all internal laryngeal muscles, which resembles the modern theory of synkinesis. Moreover he felt that the SLN through an anastomosis to the RLN controls this activity.

According to the classic theorem of the innervation of the larynx that was laid down by Longet in 1849 the superior laryngeal nerve gives the sensory innervation of the laryngeal mucous membrane only as far as the level of the glottis. The RLN is mainly a motoric nerve and its sensory fibers innervate only the subglottic mucosa (cit.:[53]). Many authors have already been debating this statement since the end of the 19th Century. The connecting branch between the superior laryngeal nerve and the RLN, the Ansa Galeni (AG) was the main subject of this contestation. Other intralaryngeal connections has been revealed by Ira Sanders [54] which may provide an individual motoric innervation of the laryngeal muscles.

Summarizing these often controversial facts we can conclude, that the recurrent laryngeal nerve injury and its regenartion process are not a “yes or no” conditions. The complex neural network, influenced by the surrounding nerves; the unpredictable and often pathological axon regeneration, the dominant reinnervation of the adductor muscles result in an individual outcome with generally the possibility of active adduction.

1.7. Etiology and Classification of Posterior Glottic Stenoses, treatment options

The posterior commissure involves the dorsal third of the vocal cords, the cricoid lamina, the arytenoid cartilages and the interarytenoid area with the interarytenoid muscles and their covering mucosa.[55] A scarring here may limit the normal motion of the glottis. [56] Due to the increase of patients undergoing assisted ventilation, the most frequent cause of posterior glottic stenosis (PGS) has become prolonged intubation in the past decades. This may lead to this complication in approximately 1% of the patients.[56] The pressure of the ventilation tube causes an edema of the mucosa which furthers ischemia as a vicious cycle. When the deeper tissue layers are affected it can cause exulceration; during the healing process granulation tissue can develop and lead to scar formation. According to Courey et al.[57] the degree of PGS is in direct proportion to the tissue depth the damaging noxa reaches. A secondary infection may also involve the arytenoid cartilages, and the resulting perichondritis may cause the scarring, or in severe cases, ankylosis of the cricoarytenoid joint. [58] This process is over within weeks after the intubation, and patients may suffer from various degrees of slowly developing dyspnea and dysphonia. This entity can also come about as a complication of surgery performed in the posterior commissure (e.g., failed arytenoidectomy [36]) or as a result of gastroesophageal reflux.[59] In children this entity is not uncommon and must be differentiated from vocal cord paralysis when there is posterior glottic fixation.[60] The etiology can help us to differentiate among these two types of immobility, but the golden standard of the diagnosis is the rigid endoscopy. Once we have justified our diagnosis as posterior glottic stenosis, we should classify the severity of the case using the Bogdasarian classification.[58]

The Bogdasarian and Olson classification of PGS is based on the tissue depth affected, hence this is the most accepted to compare different treatment results. Type I refers to a scarring between the vocal processes and type II means those that also spread into the interarytenoid space. Scarring, however, may also develop between the lower surface of the arytenoid cartilage and the cricoid cartilage, bringing about the destruction of one (type III) or both (type IV) cricoarytenoid joints.

PGS causes a pseudoparalysis of the vocal cords, so theoretically a full recovery of glottic function can be expected after the surgery.

The treatment modalities ranged from the scar excision to the crycotracheal reconstruction in combined stenosis. In adults the most common used methods are the same as the interventions treating bilateral vocal cord palsy. [61] The phoniatric outcome, even in cases of BVCP is poor. A simple scar transection, however, may only be effective in type I stenoses.[62] In more severe cases a stent or a keel is inserted,[63, 64] or coverage of the surgical defects by a mucosa flap graft[65] via external or endolaryngeal approach is used to prevent restenosis. In cases of higher grade (type III–IV) stenoses a posterior cricoid graft is suggested. [60, 66] The graft and the disruption of the anterior commissure place the voice quality at risk.[62] Donor site morbidity means further problems.[67] Application of endoscopic partial or complete arytenoidectomy, [22, 68] or transverse cordotomy, [69] is to be carefully considered, as irreversible damage to laryngeal function can occur. What is more, due to the originally damaged state of the posterior commissure, the success of these procedures may be limited in the long run.[68, 70] Proton-pump inhibitors[59] or fibroblast inhibiting mitomycin-C administered into the lesion may be applied as an adjuvant measure.[71] In children because of the narrower airways, and smaller reverse capacity, procedures aimed at increasing the airway lumen by tissue excision have not been uniformly successful. Chronic aspiration and poor voice results have been reported. [60] Expansion of the posterior glottis yields excellent results. Tracheotomy decannulation without aspiration and return of vocal cord mobility in children who have vocal cord fixation with achievement of a functional voice can be expected from widening the laryngeal framework. Scar incision without excision reduces the denuded laryngeal surface. The laryngeal framework is widened by anterior and posterior cricoid split and by stenting. Posterior cartilage grafting reduces scar tissue build-up and the duration of stenting. ne of the disadvantages that even the most successful procedures share is that the temporary tracheostomy might have to be sustained for a longer period of time. This can be avoided with functionally adequate outcomes in cases of mild to moderate stenoses (type I–III) if after scar excision an endoscopic simple suture vocal cord laterofixation is performed and sustained for a few weeks. [36, 70, 72] However, bilateral intracapsular scarring of the cricoarytenoid joint (type IV) considerably limits the applicability of this method. The question arises whether results especially phoniatric results can be improved by careful consideration of the real physiologic motion of the arytenoid cartilage during abduction. If surgical modifications that focus on better mobilization and lateropexy of the arytenoid cartilage would provide function preservation even for severe stenoses?

2. AIMS OF THE THESIS

1. To build up a standard voice panel containing objective and subjective measurements for the evaluation of voice surgery, which can be used in the everyday practice and simple enough to be adopted in an ordinary Hungarian ENT department.

2. Phoniatric evaluation of patients with Endoscopic Arytenoid Lateropexy (EAL) performed in bilateral vocal cord paralysis in the context of the reversibility and retaining voice

3. To evaluate patients with arytenoid mobilization and lateropexy in cases of posterior glottis stenoses.

4. To enhance this protocol for the suggested complex voice evaluation indexes on a well described patient population (patient underwent arytenoid lateropexy) and to examine their statistic correlation with the more time consuming Standard Voice Panel

5. To confirm the voice preservation ability of this minimally invasive intervention in different grade of PGS.
6. Invent new management options in patients groups of BVCP and PGS using our result, according to the residual functional movement recovery possibilities which could help the phonation.

3. METHODS

3.1 Objective and subjective measurements based voice assessment for the evaluation of the functional results of phonosurgical aspects of laryngeal interventions

3.1.1 Voice analysis

The voice analysis contains the evaluation of the pronounced sound wave, with objective and subjective methods as well, the patients' self evaluation and the picture analysis of the glottal structures.

3.1.2. Technical conditions and the voice recording

To perform good sample recording, we have to ensure some technical circumstances, and for the comparison of the different samples also important to perform suitable voice recording methods.

The voice recording is important for the subsequent evaluation. Some new device can perform online validation, but for the subjective evaluation, or for the "blind" subjective evaluation the recording is advised. The analogue signals of the microphone, is transformed with an analog to digital converter to digital signals in order to use an analog signal on a computer. With the increasing computer use in this field the need for digital signal processing has increased. The digital signals can be stored multiplied, sent, without quality loss later on even in some years after the recording we can perform accessory examinations. The information amount of the signal depends on the sampling frequency (discretization), and the quantization of the waveform. In the discretization stage, the space of signals is partitioned into equivalence classes and quantization is carried out by replacing the signal with representative signal of the corresponding equivalence class. In the quantization stage the representative signal values are approximated by values from a finite set.

The Nyquist-Shannon sampling theory states that a signal can be exactly reconstructed from its samples if the sampling frequency is greater than twice the highest frequency of the signal. In practice, the sampling frequency is often significantly more than twice the required bandwidth. In our practice it means that the human ear could hear the sounds up to 20.000Hz, so our sampling frequency needs to have 2x20.000 Hz. The everyday usage the CD sampling frequency is 44,1 kHz, 16bit is suitable for the examinations and the computers support this, but using a e.g. 10kHz sampling frequency we would lose all the noises, and harmonics above 5kHz and so we would lose one part of the information because the human voicing contains sounds up to 10 kHz. We suggest the sampling frequency of 20 kHz if possible, and to reduce the noise of the computer with a silent power supply.

The commercially available voice analysis softwares contain recording and archiving functions. If we would like to perform our own recordings, the Windows© own recording function is not suitable for voice analysis alone, but we can reach quite good noise reduction with freeware program like (Audacity http://audacity.sourceforge.net/ , Praat www.fon.hum.uva.nl/praat/). For the storage of the recorded sounds the wav extension is adequate which is widely accepted, and known by all sound analysis softwares and without loss of information like the compressed formats such as wma, or mp3. For the voice recording a silent room is sufficient (noise level under 40 or 50 dB), we do not need a silent camera used for audiological measurements. The microphone distance should be constant; the most common suggestion is between 15 and 30 cm. The most important thing is to stick with the same distance once selected and microphone holders should be provided to keep the same distance during the experiments. The axis of the microphone should differ 45-90 degree from the acoustic axis to reduce the noise caused the dynamic of the airflow. [73, 74] (Figure 2)

Figure 2: The normal position of the patients and the microphone during voice analysis.

Microphones can be classified by their transducer principle, such as condenser, dynamic, etc. Dynamic microphones function via electromagnetic induction. They are robust, relatively inexpensive and resistant to moisture. This coupled with their potentially high gain before feedback makes them ideal for on-stage use. In a condenser microphone, also called a capacitor microphone or electrostatic microphone, the diaphragm acts as one plate of a capacitor, and the vibrations produce changes in the distance between the plates. They generally produce a high-quality audio signal and are now the popular choice in laboratory and studio recording applications. The inherent suitability of this technology is due to the very small mass that must be moved by the incident sound wave, unlike other microphone types that require higher sound pressure. They require a power source, provided either via microphone outputs as phantom power or from a small battery. The recording sounds more natural. Because of the above mentioned advantaged we suggest high sensitivity condenser microphones.

In the international literature most commonly the [a:] and [i:] sound are analyzed. The European phoniatric association suggest [a:] but in the American literature we often find [i:]. Our opinion is in line with Frint [75] stating that for the noise components between 2-4 kHz [i:] is more sensitive. In everyday practice together with ELS we agree that the sound [a:] is suitable for voice analysis. Voice recording is performed in the described way.

1. After maximum inspiration the longest sustained vowel e.g. [a:] in a comfortable pitch and intensity. For MPT, Jitter, Shimmer, HNR measures. The recording is repeated for three times to give the possibility of measuring the constancy of the voice quality.

2. Sustained vowel e.g. [a:] in a forced intensity to measure the frequency sound pressure regression line, also give the possibility to measure the constancy of the voice quality. There are cases where the closing of the glottis is only performed in high intensities.

3. Recording the highest and lowest frequency. For voice range profile.

4. Counting from 1 to 20 every even number with the highest every odds number with the lowest intensity, but not whispering. For intensity measurement, voice range profile.

5. A given text or sentence recording with comfortable pitch and intensity for subjective analysis. (Names of the months, or the weekday is also possible) the given text possibly not to contain many (s, sz, z, zs), they elevate the noise component.

For the "Standard Voice Panel" suggested in the everyday practice the 1st recording sample is sufficient.

3.1.3. Objective voice parameters (Aerodynamics, Acoustics)

The simplest aerodynamic parameter is the maximum phonation time MPT in seconds. It is measure after maximum inspiration the longest sustained vowel e.g. [a:] in a comfortable pitch and intensity. The examination is very simple only a stopwatch required and this measurement is the most widely used.[76] Advised to repeat the measurement 3 times and we register the longest value. [77] Also suggested showing the tasks to the patient. This task is not physiological in terms of phonation; it is very sensitive for the learning and the fatigue. Children show significantly lower values of MPT as their lung volume is smaller. [78] To decrease the difference among age groups the mean phonation flow was introduced in a more commonly used name Phonation Quotient (PQ). PQ=Vital Capacity (VC) (ml)/MPT(s) The vital capacity can be measured also with using a hand-held spirometer. [79] In normal subjects, VC depends on anthropometric factors, and it is quite strongly correlated with height, for example[80]. It is also sensitive to lung disease. As VC is not directly correlated to voice quality, it is sensible to take it into account, especially when children are being investigated. The mean air flow rate can also be measured by using a pneumotachograph. This device provides a direct measurement of the mean airflow rate (ml/s) for sustained phonation over a comfortable duration, usually 2-3 s, at the habitual pitch and intensity level and following inspiration of a habitual kind. Normal values have been reported in many authors [76, 81-84]. The variation of averaged phonation airflow varies considerably among normal subjects, and there is a large overlapping range of values in normal and dysphonic subjects. This limits its value for diagnostic purposes, nevertheless, when glottal function before and after surgical intervention or nonsurgical voice training techniques are compared, airflow measurements may be very useful for monitoring therapeutic effects [85, 86]. For comparison the pre- and post treatment measurement, advisable to use the same kind of technique. There are new attempts to introduce new measurements not depending from the lung function, measuring the rate between aerodynamic values and glottis area –measured by digital picture analysis from videostroboscopic pictures- [21] In these new inventions we think the biggest advantage of the aerodynamic parameter, the simplicity will be lost.

The acoustic parameters provide objective and noninvasive measurement of vocal function. Increasingly, these measures have become available at affordable cost and they appear to have been very successful for monitoring changes in voice quality over time. Perturbation measures (the constancy of the wave form in period Jitter and in amplitude Shimmer) and harmonics to noise ratio (HNR) computation [87] have emerged as the most robust measures, (HNR is expressed in dB: if 99% of the energy of the signal is in the periodic part, and 1% is noise, the HNR is 20 dB. A HNR of 0 dB means that there is equal energy in the harmonics and in the noise) and seem to determine the basic perceptual elements of voice quality: Grade, Roughness, and Breathiness [88, 88, 89]. A general limitation is that the systems employed for acoustic for analysis cannot (or not in a reliable way) analyze strongly aperiodic signals. Perturbation measures become unreliable if the voice signal contains intermittency, strong subharmonics or modulation. Therefore, a visual control of the period definition on the microphone signal or of the spectrogram is always necessary even is regular voices, a strong harmonic or subharmonic may account for erratic values [74, 90]. There are insufficient standardization of the optimal algorithm(s), e.g. for signal-to-noise ratio computations. These are HNR harmonics-to-noise ratio, NNE normalized nose energy, cepstrum peak etc. Thus, at present, percent jitter, and percent shimmer are proposed as the basic acoustic measures, to be computed on a sustained [a:] at comfortable frequency and intensity. Jitter is computed as the mean difference between the periods of adjacent cycles divided by the mean period. It is thus a F0 (fundamental frequency)-related measurement. For shimmer, a similar computation is made on peak-to-peak amplitudes. Voice breaks must always be excluded. If any other algorithms are used they need to be clearly specified. Obviously, comparisons of pre-/post treatment voice qualities require similar techniques and material.

All above mentioned measurements could be assessed on-line (prompt result is available at the time of recording) or in a recorded, stored voice sample, off-line mode (hours, days, months or years later than the recording). The on-line devices price is higher, but the modern videostroboscopes contains the software providing these values. The most commonly used programmes are MDVP (Multidimensional Voice Profil) or Praat software. The Praat software is a freeware. Downloadable from http://www.praat.org or http://www.fon.hum.uva.nl/praat sites. [91]

In Praat software for the measurement of different acoustic parameters in a row a files, it is possible to automated by writing small scripts. Our results will be delivered in *.txt file. [92].

Between exact values, we can also visualize the spectrum of the voice. (Figure 3, 4)

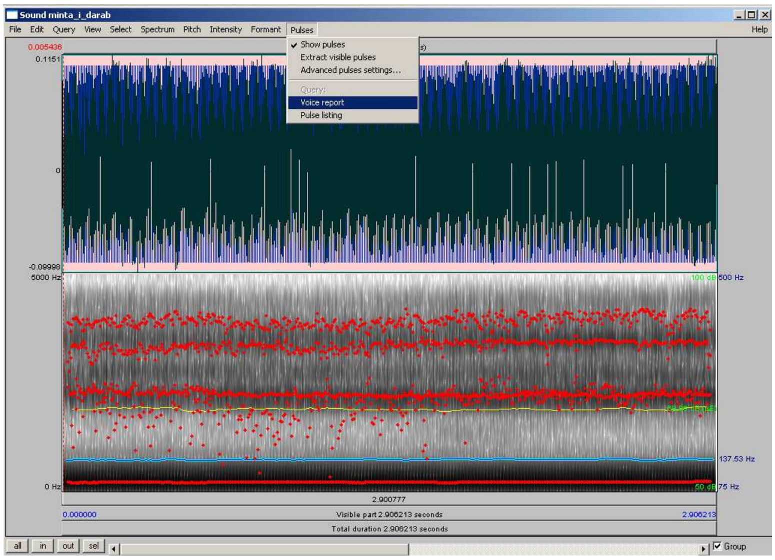

Figure 3: The graphic visualization of a voice sample in the lower part of the picture we can see the traditional spectrogram (gray scale) the pitch (blue) formants (red)

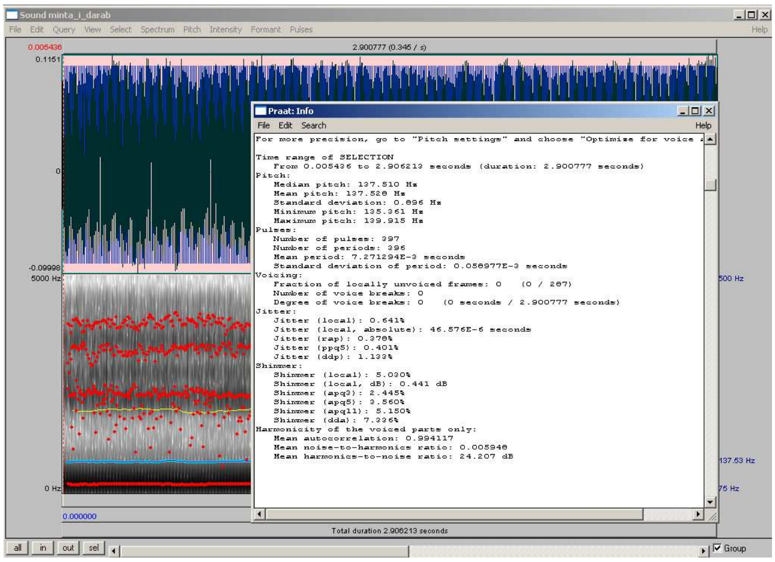

Figure 4: The numeric values of the examined voice sample (Pitch, Jitter, Shimmer, Noise to harmonic ratio, etc.)

The used algorithm is slightly different, but some authors said Praat is more accurate. [93] The comparisons of different programmes provided results as with the pre-/posttreatment voice qualities requires possibly similar techniques[94]. In the acoustic analysis, all vowels have their own normal values.

3.1.4. Subjective voice analysis (RBH-system, Measuring voice range profile)

Current research does not support the substitution of instrumental measures for auditory–perceptual assessment. However, it is well known that semantics regarding definition of dysphonia and hoarseness are a critical matter: social and cultural aspects have a great importance for what is considered breathy or harsh voice quality [95] . It is proposed that the term ‘dysphonia’ be used for any kind of perceived voice pathology: the deviation may concern pitch or loudness, as well as timbre or rhythmic and prosodic features. ‘Hoarseness’ is limited to deviant voice ‘quality’ (or timbre), and excludes pitch, loudness and rhythm factors. A limited number of voice pathology categories, such as those related to mutation or transsexuality, are specifically concerned with pitch. Rhinophonia is a specific abnormality of resonance – and needs to be reported separately, if present. However, the assessment of treatments for rhinophonia (aperta or clausa) does not fall in this scope. Prof Hirschberg has examined the phoniatric changes during rhinophonia [18, 96]. Tremor is a characteristic temporal feature, and must also be reported separately, when present. The rating is made on current conversational speech (anamnesis of patient). It is also possible to grade the handicap of the voicing by perception also in cases of recorded voice sample [97].

The severity of hoarseness is quantified under the parameter G (grade) from the GRBAS scale proposed by Hirano [76] : it means the overall voice quality, integrating all deviant components. Two main components of hoarseness have been identified, as shown by principal component analysis: (1) Breathiness (B): audible impression of turbulent air leakage through an insufficient glottic closure may include short aphonic moments (unvoiced segments). (2) Roughness or harshness: audible impression of irregular glottic pulses, abnormal fluctuations in Fo, and separately perceived acoustic impulses (as in vocal fry), including diplophonia and register breaks. When present, diplophonia can be additionally recorded as “d”. These parameters have shown sufficient reliability (inter- and intraobserver reproducibility) when used in a current clinical setting [88, 98]. The behavioral parameters ‘asthenicity’ and ‘strain’ are currently less reliable and have been omitted from the basic protocol. The remaining simplified scale, GRB, then becomes similar to the RBH scale (Rauhigkeit for roughness, Behauchtheit for breathiness, and Heiserkeit for hoarseness) used in German speaking clinics [99]. The latter one was published in Hungarian by Mészáros [100]. For reporting purposes, a four-point grading scale is convenient (0, normal or absence of deviance; 1, slight deviance; 2, moderate deviance; 3, severe deviance), but it is also possible to score on a visual analogue scale (VAS) of 10 cm, with anchoring points [88, 101].

VRP: voice range profile [102] measures (lowest intensity, highest intensity, lowest frequency, highest frequency) can also give much information about the phonation, and used in many complex evaluation scales. Also included in the basic acoustic measures are three critical points of the phonetogram. The highest frequency and the softest intensity (dB A at 30 cm) seem to be the most sensitive for changes in voice quality [103-105], the latter being related to phonation threshold pressure [106, 107]. The measurement of the lowest frequency makes it possible to compute the fundamental frequency range. Such a ‘threepoint phonetogram’ can be obtained without completing a (time-consuming) whole voice range profile. However, as these three points represent ‘extreme’ performances, they, like MPT and CV, are very sensitive to learning and fatigue effects.

Measuring the whole voice range profile is commonly used in the German speaking area, used a standardized text of La Fountaine tale. The Sun and the North Wind. (Einst stritten sich Nordwind und Sonne….) The Hungarian translation and validation of the text is under process by Krisztina Mészáros and Tamás Hacki.

3.1.5. Subjective self evaluation (Voice Handicap Index)

This evaluation of voice, although subjective by definition, is of growing importance in daily clinical practice. It is the patient who has to live with his/her voice. Also, social and cultural aspects may be relevant in consideration of voice quality. This evaluation needs careful quantification, as it is paramount and needs to be compared and correlated with the data of the objective assessment. In the international literature two main evaluation methods are described.

1). A minimal subjective evaluation can be provided by the patient himself on a double visual analogue scale of 100 mm: the impression of the voice quality in the strict sense, and the impression of what repercussions the voice problem has on everyday social and, if relevant, professional life and activities. A score of ‘0’ (extreme left) means normal voice (no deviance) on the first scale and no disability or handicap (related to voice) in daily life on the second scale, while ‘100’ (extreme right) means extreme voice deviance on the first scale and extreme disability or handicap in daily social (and, when relevant, professional) activities, as rated by the patient. The basic aim is to differentiate the deviance of voice quality in the strictest sense, and the severity of disability / handicap in daily social and/or professional life.

2.) In the last years the most commonly used test for self evaluation is the voice handicap index (VHI) [108] can be computed on the basis of a patient’s responses to a carefully selected list of questions: besides the aspects already mentioned, it also investigates the possible emotional repercussion of the dysphonia. The Hungarian translation of this test was introduced by our workgroup. (Appendix1) The questionnaire contains 30 items in 3 subscales (functional, emotional, and physical [10 items in 3 subscale] (F=function, P=physiology, E=emotion), designed to quantify patients’ self-assessment of everyday voice handicap. Answers are given in 5-point scale ranging from 0 (never) to 4 (always). The overall VHI score (raw score) can be used to grade subjective handicap from 0 (no handicap [raw score, 0—14]) 1 (mild handicap [raw score, 15—24]), 2 handicap [raw score, 25—50]), 3 (severe handicap [raw score 51-120]). It is described VHI for professional voice users and children as well [109-111]. We can find 10 questions contained, shortened

VHI, but the clinical usefulness of this version is limited. [112, 113]. According to our opinion the VHI test is a useful tool, and with the subtests, ∑P, ∑F, ∑E can validate our treatments affectivity and the necessity of our further interventions, or treatment modalities.

In cases of oncological diseases, (surgical tumor excisions, post operative radiotherapy etc.) the lack of the soft tissues of the larynx do not allow us to use the VHI, in these cases the general life quality if more determining, and for validating our results it is suggested to use the QoL (European Organization for Research and the Treatment of Cancer quality-of-life questionnaire), which have special tool for the head and neck oncology patients.

In Hungary the usage of this questionnaire is described by Kiefer and Fent. [114]

3.1.6. Indexes for measuring the overall quality of the voicing

Dysphonia Severity Index (DSI)[115] is designed to establish an objective and quantitative correlation of the perceived vocal quality to evaluate the therapeutic evolution of dysphonic patients. DSI 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

Normal voices equals +5 and for severely dysphonic voices –5. The more negative the DSI, the worse the vocal quality will be. DSI can reach values under –5 and above +5 as well.

Friedrich introduced a dysphonia index to evaluate the treatment affectivity in cases of unilateral vocal cord palsy. [10] Friedrich’s Dysphonia Index (FDI)[10] uses the average of 5 subscales each ranges from 0 (normal) to 3 (severe handicap). These subscales are MPT, DR, FR, and limitation in communications (subjective scale). The highest the score, the worse the voice quality will be. (Table I)

The subscales are:

1.) Roughness from GRBAS scale,

2.) Maximum Phonation time was measured how long the patient could sustain of the sound “a” after inspiration (normally 18-20 seconds).

3.) With the aid of Voice range profile measurement (sec. Hacki[116]) the following were measured: 1) minimum and maximum values of habitual speaking pitch (while reading a standard text) voice frequency. Voice pitch range was measured by half tones/semitones (ST) and

4) Vocal intensity or dynamic range (DR) was measured in decibels. (The microphone was placed at a distance of 30 cm, and it had an “A” filter.), (sec.Hacki[116]).

5) In the original Friedrich’s evaluation Communicative impairment was determined by the patient. We used the VHI test to grad the degree the person’s voice for communication. VHI 0-14 means 0 = no limitations; VHI 15-24 means1 = limited communication only in the case of voice load, VHI 25-50 means 2 = a small degree of constant limitation, VHI>50 means 3 = constant strong limitation in everyday communication.

Values of subscales	Hoarseness G value from GRB scale	Frequency range In semitones	Dynamic Range Decibel	Max. Phon. Time sec	Impairment of communication VHI
0	G0	>24	>45	>15	<15
1	G1	24-18	45-35	15-11	15-24
2	G2	17-12	35-25	10-7	25-50
3	G3	<12	<25	<7	>50

Table I: The values of the different subscales in Friedrich’s disphonia index. The disphonia index is the mathematical average of the 5 subscales.

The FDI is the mathematical average of these 5 subscales ranging from 0 (no deviance) -to 3 (severe deviance)

3.1.7. Subjective analysis of videostroboscopic pictures

Videolaryngostroboscopy is the main clinical tool for the etiological diagnosis of voice disorders. It is available in many ENT departments of the hospitals and even in the private practices and can also be used for assessing the quality of vocal fold vibration, and thus the effectiveness of treatments, medical or surgical. The examination has two modes, the stationer, and the slow motion. With a voice base frequency following, or approximated flashing light, we can see a virtual still, or slowed picture. The pertinence of stroboscopic parameters is based on a combination of reliability (inter- and intraobserver reproducibility), nonredundancy (from the factor analysis), and clinical sense (relation to physiological concepts). Basic parameters are:

(1) Glottal closure: quantitative rating using a four-point grading scale, or a visual analogue scale of 10 cm (see above). It is recommended that the type of insufficient closure also be recorded and categorized:

– Longitudinal: over the whole length of the glottis and without sufficient adduction

– Dorsal (posterior triangular chink): it is, however, important to consider that a slight dorsal insufficiency – even reaching into the membranous portion of the glottis – occurs in about 60% of middle aged healthy women during normal voice effort. In 50% of women the glottis is completely closed when they are speaking in a loud voice

– Ventral

– Irregular

– Oval: over the whole length of the glottis, but with a dorsal closure

– Hour-glass shaped [88, 117, 118]

(2) Regularity: quantitative rating of the degree of irregular slow motion, as perceived with stroboscopy [119].

(3) Mucosal wave: quantitative rating of the quality of the mucosal wave, accounting for the physiology of the layered structure of the vocal folds .[76]

(4) Symmetry: quantitative rating of the 'mirror' motion of both vocal folds. Usually asymmetry is caused by the limited vibratory quality of a lesion (e.g. diffuse scar, or localised cyst or leucoplakia) [120].

For each stroboscopic parameter, a four-point grading scale (0, no deviance; 3, severe deviance), or a visual analogue scale can be used [88, 121]. Videostroboscopy can be documented on a hard copy, and thus be archived. Rating 'a posteriori' is possible. It is classically recommended videostroboscopic pictures be observed and recorded in different voicing conditions. For example, the degree of glottal closure usually increases with increasing loudness. However, this basic rating concerns the comfortable pitch and loudness. For comparisons (pre-/posttreatment), it is advisable to use the same kind of endoscope (rigid or flexible, if rigid: same angle e.g.:70^0, 90^0) at each examination.

In some cases the base frequency of the vocal cords is not permanent, especially at the beginning of the phonation so the videostroboscopy can deal with the irregularity. In such cases the high speed glottography can help us to clarify the hoarseness. A 4000 picture/sec recording gives excellent possibility to evaluate e.g. the rigidity of the vocal cords of the slightest mucosal abnormalities.

In a recorded videostroboscopic file the evaluation can be done blindly by different examiner even after years of the recording.

3.1.8 Our suggestion for a Standard Voice Panel in Hungary for everyday Practice and its completing for scientific comparison

The above described complex, often parallel measurements required by the scientific work up. In our everyday practice we use a more reliable time and device consuming group of examinations.

We give an example for the Standard Voice Panel in a case of an 18 year old female with unilateral vocal cord palsy demonstrating a more simple and suitable protocol.[122] Table II. shows the examined parameters before and after lipoaugmentation of the paralyzed vocal cord.

These parameters are: Maximum Phonation Time (MPT), Base Frequency (Pitch), Harmonic-to-Noise ratio (HNR), Jitter%, Shimmer%, Perception G,R,B (Grade, Roughness, Breathiness), Voice Handicap Index (VHI), Videostroboscopy: Closing (Clo), Regularity (Regul)., Mucosal wave (MW), Symmetry (Sym)

	Aero-dynamics	Acoustics				Perception 0-100				Vidoestroboscopy			
	MPT (sec)	Pitch (Hz)	HNR (dB)	Jitt %	Shim %	G	R	B	VHI	Clo.	Regul.	Mucosal wave	Sym
Before	5	219	13.9	1,1	10,8	40	40	80	43	60h	30	30	50
After	22	232	21,2	0,3	2,6	10	20	10	13	20d	10	10	25

Table II: Standard Voice Panel for the evaluation of an 18 year old female before and after lipoaugmentation. All evaluations were performed blindly by 3 independent ENT professionals on a recorded sustained phonation of vowel [a:] and in a recorded videostroboscopic file. Perception and videotroboscopy were rated on visual analogue scales each 100mm long, 0 always means normality (no deviance) and 100 extremely deviant. MPT: maximal phonation time, Pitch: Fundamental frequency (F0), HNR: harmoics-to-noise ratio, Jitt: Jitter%, Shim: Shimmer %, G: severity of hoarseness, B: breathiness, R: roughness or harshness, VHI: Voice Handicap Index, Clo: closure, h: horizontal, d: dorsal, Regul.: regularity, Mucosal wave: quality of mucosal wave, Sym: symmetry

Besides the above mentioned "Standard Voice Panel" evaluation, we suggest to use more examinations, as dynamic range (in decibel)[116], frequency range (mostly used in semitones)[116], and complex dysphonia indexes as dysphonia severity index (DSI)[115] and Friedrich's Dysphonia Index (FDI)[10]for the better comparability of the results with the international literature.

3.2 .Surgical procedure: Endoscopic Arytaenoid Lateropexy and Arytenoid Mobilisation

Bilateral vocal cord immobility (BVCI) is a broad term used to describe vocal cords that are restricted secondary to neuropathy, muscular disorders or mechanical fixation (MF) [20]. The moderate to severe dyspnea generally requires surgical intervention. However, the recently suggested endoscopic treatment modalities [23, 123] may restore the airway patency in bilateral vocal cord paralysis (BVCP) but treatment of MF often requires external procedures (laminotomy with or without arytenoidectomy etc.) [35, 60]. Potential reversibility of BVCP means a further therapeutical challenge which necessitates a complex preoperative assessment [27] and gradual application of those techniques which resects the glottic structures [22, 23].

Our earlier studies demonstrated long-term dependable results, if the arytenoid cartilage is directly lateralized to the *normal abducted position* [124] by endoscopically inserted sutures. We observed benefit of this procedure not exclusively in BVCP [30] but even in severe cases of MF after proper mobilization of the cricoarytenoidal joint (CAJ) [70]. Nevertheless, the correct creation of this more posterior location of fixating loop is practically impossible through an externally inserted needle as it described by the Ejnell’s procedure [32]. This special suture placement is also a challenge for the original Lichtenberger device [31] because the thyroid cartilage is more dense in that area. Moreover, these techniques share a common problem: fixating threads are led through the oral cavity, which increases the well-known risk of perichondritis, the main complication of these procedures [30]. For this reason, as demonstrated by the result of a series of BVCI patients with different etiology, a new procedure performed with the prototype of an endolaryngeal instrument is introduced here. This thread guide device is purposely designed for safe, accurate and fast suture loop creation for the endoscopic arytenoid lateropexy (EAL).Endoscopic arytenoid lateropexy (EAL) [70, 125]. means the endoscopic creation of suture loop(s) *around the arytenoid cartilage* according to its physiological abduction, thereby providing immediate and stable airway restoration [70]. Because of the peculiarity of laryngeal anatomy this procedure requires special device. In the first 6 patients a reinforced Lichtenberger needle-carrier instrument [70] was used and the other 24 patients a new endolaryngeal thread guide instrument (ETGI) [125] designed for the further optimization of this method [30, 31, 36]. (Figure 5) The sutures were removed from a small skin incision if vocal cord recovery had been endoscopically detected. After receiving accurate information about the possibility of declining voice quality, all of the patients chose EAL instead of tracheotomy or the “watch and wait” policy. The study was approved by the Institutional Review Board of the University of Szeged.

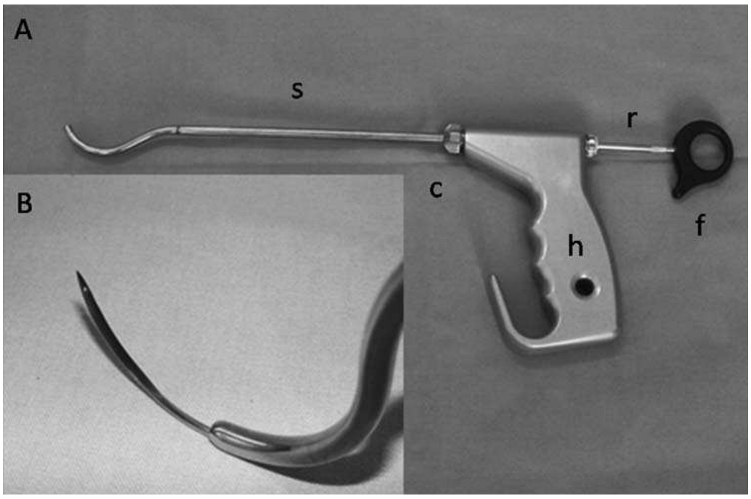

Figure5:
(A) The endo-laryngeal thread guide instrument (ETGI). (A) The parts of the ETGI (the blade is pulled back). (B) The built-in, movable, curved blade in a pushed-out position with a hole at its tip. s = steel pipe stem; r = rod; h = handle; c = clamping screw; f = finger clip.

The principle of the ETGI is the utilization of a built-in, movable curved blade with a hole at its tip (Figure 5 B) allowing a suture thread to be guided in-and-out between the exterior surface of the neck and the internal laryngeal cavity. The stem of the instrument is rigid steel pipe, curved at its distal, 'blade-holding' end, created to fit into mid-sized, closed laryngoscopes. The second component is a rod, largely cased within the steel pipe stem. At the un-cased, proximal end of the rod is a freely rotating 'finger clip'. At the distal end of the rod is the curved blade; appropriately designed to fit the curvature of its stem casing. The connection between the blade and the rod is fixed but flexible; ensuring forceful blade movement on exit and re-entry of the curved stem-end. The pull and push of the finger clip (with the thumb) causes the in-and-out blade movement from the stem-end. At rest, the blade is inside the curved stem-end. The third component of the instrument is the ergonomic handle, which also serves as a shaft to hold the instrument in a straight position. The steel stem of the instrument is fixed to the handle with a clamping screw after turning it to the desired direction. The structural rigidity of the ETGI ensures easy penetration through the thyroid cartilage. The device possesses the approval of the Hungarian Health Care Institute.

General anesthesia combined with supraglottic jet ventilation is suggested. For the sake of maneuverability, the larynx is exposed with usually a Weerda laryngoscope (Figure 6 A)

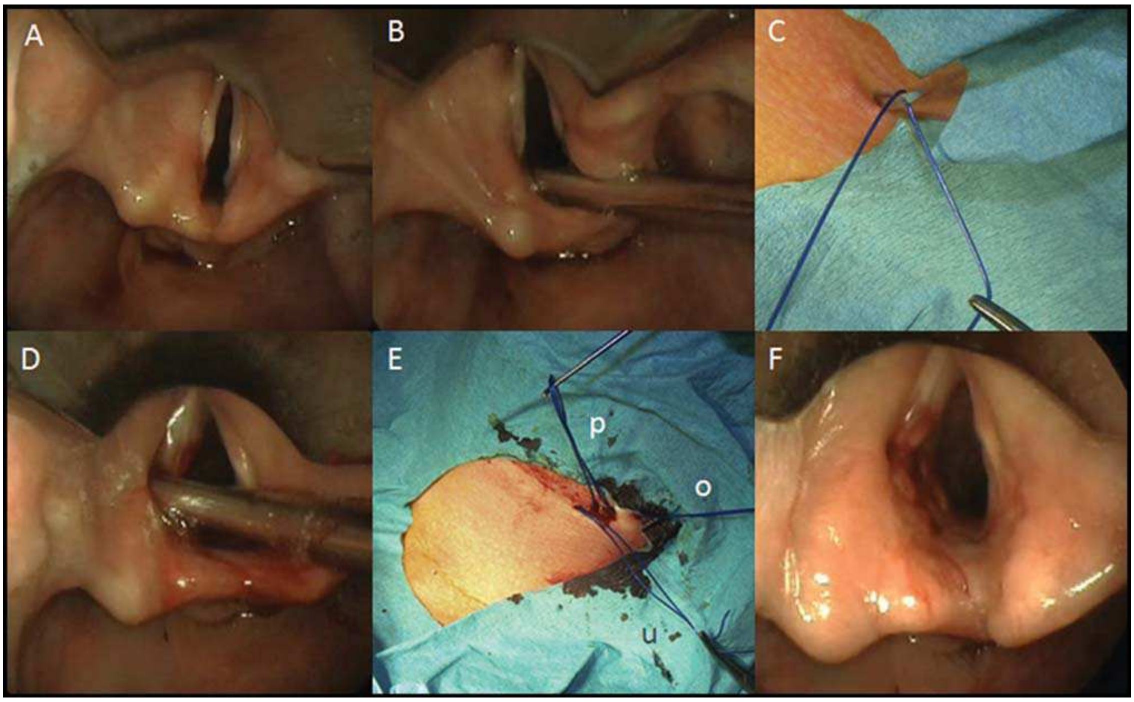

Figure 6: Intraoperative pictures of a 67-year-old female demonstrate the efficacy of the method even in a small female larynx (see detailedexplanation in the text); ends of threads situated under the vocal process (u); ends of threads situated over the vocal process (o) are just being pulled back (p) under the skin through a small skin incision by a Jansen hook.

or sometimes with a Macintosh laryngoscope (in 3 females with difficult direct laryngoscopy). In cases of MF a strong, right-angled, saber-shaped scythe designed by our team (Figure 8) used for dividing the adhesions in CAJ which may be completed with CO2 laser scar excision [70](10–15 W, continuous mode, Lasram Opal-25) under microscopic control. Afterwards the mobility of the cricoarytenoid joints was examined by passive mobilization to decide the type of the stenosis. In cases of BVCP unilateral, in cases of MF bilateral EAL was performed.

After disinfection of the mucosa the ETGI is led through the laryngoscope to the glottic level. The mobile (or mobilized) arytenoid cartilage is *tilted backwards and upwards* with the end of the instrument (Figure 6 B). The built-in, curved blade is then pushed through under the vocal process out to the surface of the neck (Figure 7 A).

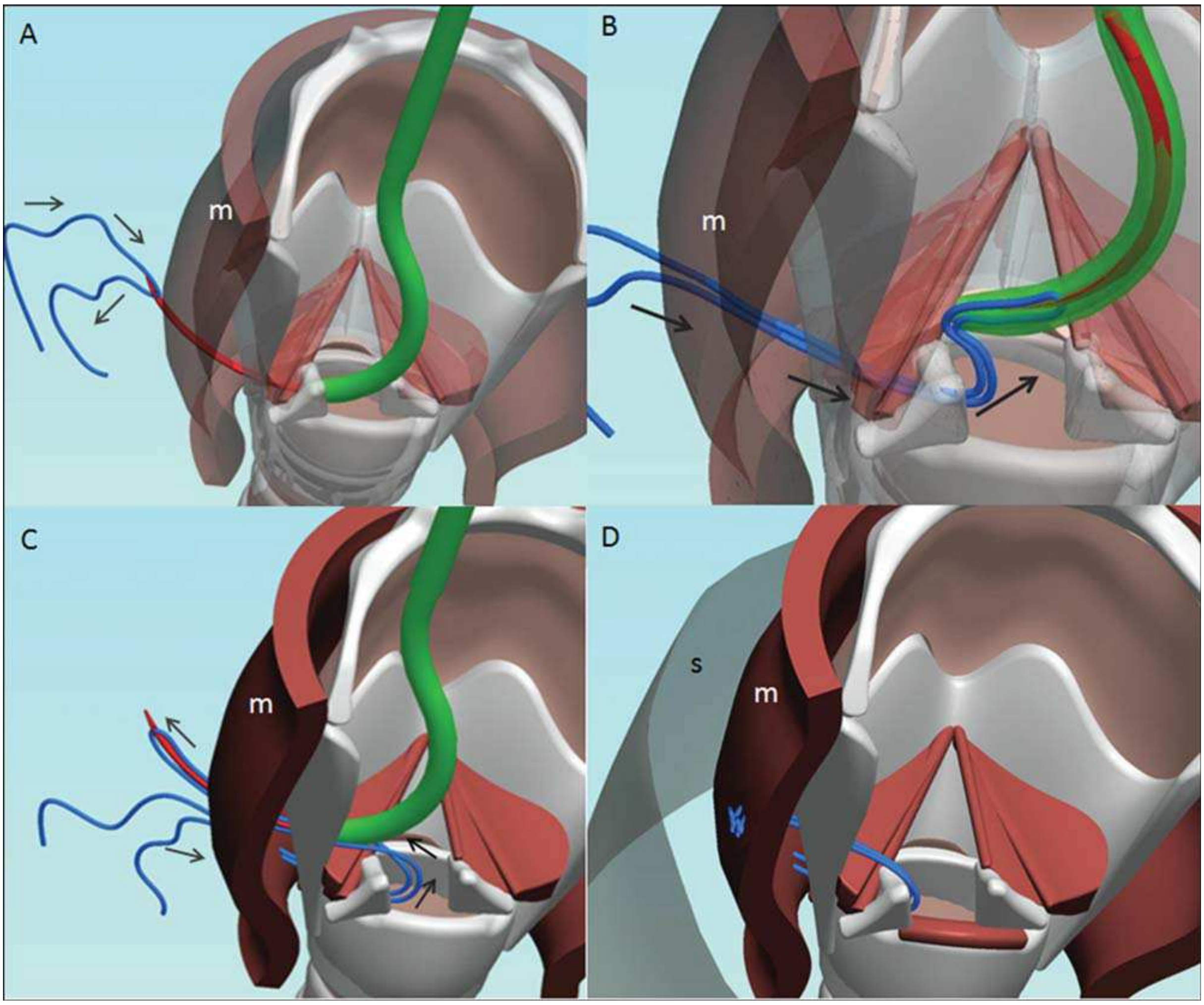

Figure 7: Schematic drawing of the procedure (detailed in the text). The skin (s) is illustrated only on the last picture to achieve better visualization. Arrows indicate the direction of the thread guiding. (m) = sternohyoid muscle.

A non-absorbable suture thread (Prolene 1.0, Ethicon, Somerville, New Jersey) is laced through the hole at the tip of the blade by an assistant surgeon (Figures 6 C and 7 A). The doubled-over thread is pulled back with the blade, into the laryngeal cavity (Figure 7 B). After a repeated tilting of the arytenoid cartilage (Figure 6 D), the blade is pushed out with the thread above the vocal process to the outer surface of the neck (Figure 7 C). The assistant surgeon then cuts the double-folded thread to remove it from the blade tip. The blade is then pulled back into the laryngeal cavity and the ETGI can be removed. A small skin incision (approximately 5 mm) is then created to withdraw the ends of the thread by a Jansen hook to the surface of the sternohyoid muscle (Figure 6 E). The corresponding ends are knotted above it (Figure 7 D). This simple procedure enables the endoscopic creation of *two* 'fixating loops' in one step at suitable laryngeal locations; providing maximal physiological abduction of the arytenoid cartilage (Figures 6 F and 7 D) within five minutes.

In case of posterior glottic stenosis (PGS) topical Mitomicin-C application is considerable [70, 71, 126]. In the peri- and postoperative period the patients were administered antibiotics (usually 2 x 750 mg cefuroxime) and 2 x 250 mg methylprednisolone for 2 to 5 days intravenously and speech prohibition are suggested for a week till the end of the healing process [70]. Hospitalization period is about 3-4 days.

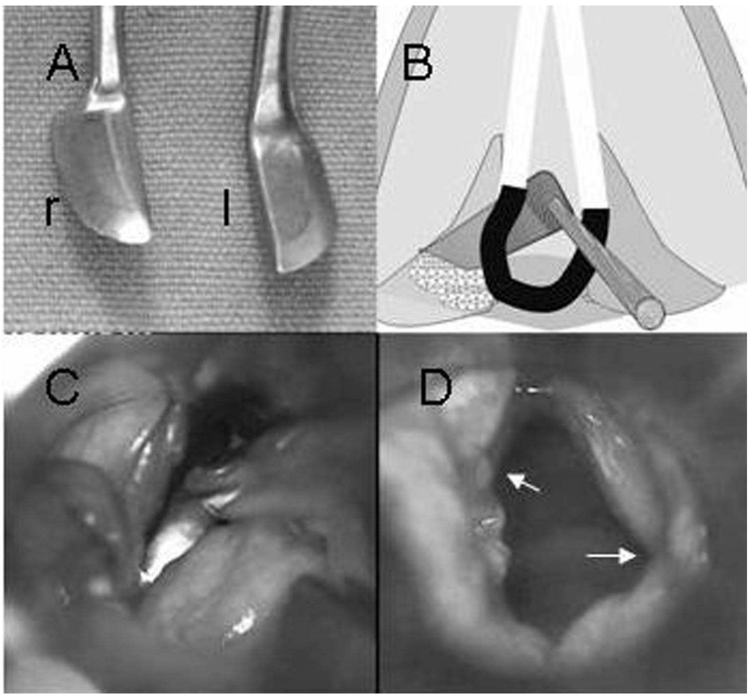

Figure 8:Mobilization of the arytenoid cartilage at the scarring of the cricoarytenoid joint (32-year-old female patient with cannula, type IV stenosis. (A) Sabreshaped blades of the endolaryngeal scythe (Fig. 7A). To increase rigidity and for the protection of the conus elasticus only one side is sharp (r: right, l: left). (B) Schematic figure of the operation (thick black line indicates the margins of the scar tissue removed with the CO2 laser from between the arytenoid cartilages, the textured area represents the intracapsular scar). (C) The scythe is guided under the vocal process and the scar fixing the arytenoid cartilage is transected along an arch. (D) Intraoperative picture of bilateral arytenoid lateropexy after proper mobilization.

The laterofixing sutures were removed via a small skin reincision in cases of pareses after the onset of the abduction movements, in cases of MF after 4 to 8 weeks, once re-epithelization in the posterior commissure was endoscopically confirmed.

3.3 Study population

3.3.1 Patients with Bilateral Vocal Cord Palsy

Between January 2004, and March 2009 thirty-six consecutive patients were sent to our department because of BVCP caused by thyroid, or parathyroid surgery. Their moderate to severe dyspnea was treated by EAL. Four of these patients did not contribute in the study, hence thirty-two of them; 29 female (90.6%) and 3 males (9.4%), with a mean age of 49.35 years (range 24-82 years; were enrolled for the phoniatric assessment. Their thyroid surgery was performed in 23 patients (70.9%) 2 days to 6 months before our admission, and for 9 patients (29.1%) more than 6 months (6 months to 3 years).

The time of complete phoniatric evaluation was 1 year after the EAL, or after the removal of the laterofixating thread in those cases in which vocal cords' complete recovery was detected.

Respecting the phoniatric results, the patients could be categorized into five well definable groups according to recovery of their laryngeal activity at the end of the first postoperative year. In group I there were 7 patients (6 female and 1 male) with complete recovery of both vocal cords. In these cases the fixating sutures were removed between 2-14 months (avg. 5.4 months) following the onset of paralyses. Six females with recovery unilaterally of their vocal cords were the members of group II. Their vocal cord regained full activity on the contralateral side of the EAL in 5, and on the side of EAL in 1 case. Their fixating sutures were removed between the postoperative 2-6 months (avg. 3.8 months). The group III consisted of 8 patients (7 female and 1 male), in which the vocal cord recovery was only partial, dominantly with adduction improvement. In these cases the fixating sutures were not removed to sustain the adequate airway. In group IV and V no significant motion recovery was detected in the glottic level. However, there was a notable difference, that in the case of 6 patients of the previous group (5 females, 1 male), well defined ventricular phonation could be observed. In the last group (5 females) practically no effective motion was detected in the larynges so these patients were considered to have complete permanent paralyses.

3.3.2. Patients with Posterior Glottic Stenoses

From September 2005 to December 2009, 21 patients (9 females, 12 males) were diagnosed and treated for PGS at our department. During the follow up we lost one patient because of advanced esophageal tumor. Thus the study group contained 20 patients (9 females, 11 males). The ages ranged from 15 to 74 years with a mean of 43 years. No further scarring or stenosis was detected in these patients in the glottis, subglottis or trachea. The etiology was prolonged intubation in 18 cases. In two patients the stenosis developed after failed unilateral (one case) or bilateral (one case) arytenoidectomy performed as a solution for bilateral vocal cord paralysis. In another patient radiotherapy for oropharyngeal tumor was the cause. To evaluate the efficacy of the method suggested in higher grade stenoses, the patients were divided into two groups according to the severity of PGS. The first group (Group A) contained 9 less difficult cases in which scarring involved only one (if any) cricoarytenoid joint (Fig. 9A). According to the Bogdasarian and Olson classification there were eight type II, and one type III stenoses in this group.

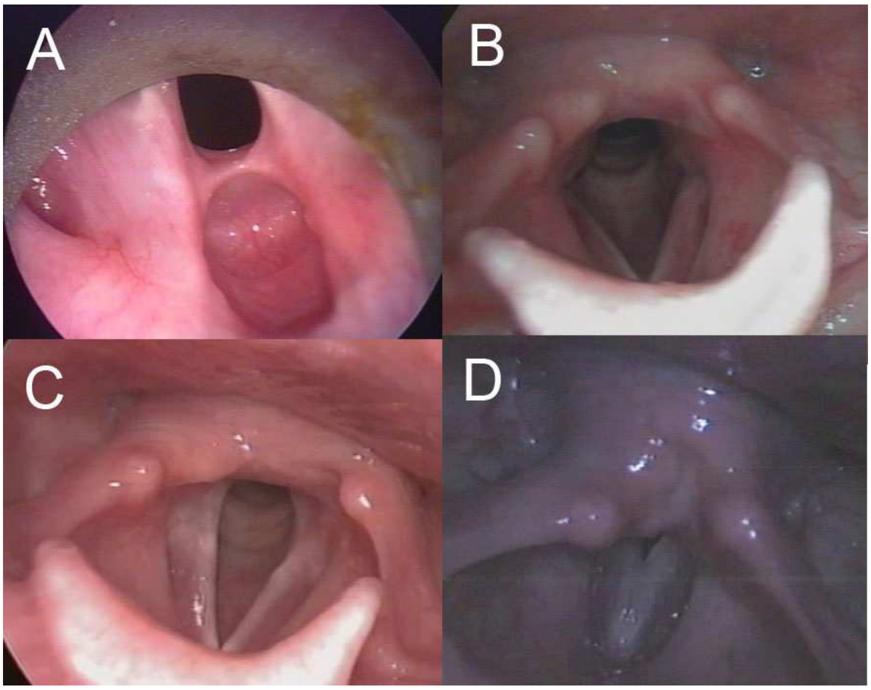

Figure 9: Type II stenosis (28-year-old female). (A) Scar between the arytenoid cartilages intraoperatively (PIF: 1.2 l/s). (B) Two days after operation the arytenoid cartilages are fixed in an abducted position (PIF: 2.8 l/s) (arrows indicate the fixing sutures). (C) Inspiratory picture of the larynx 6 months after removal of the fixing sutures (PIF: 3.2 l/s). (D) A small closure deficiency detectable only between the vocal processes at phonation (stationary stroboscopy).

The second group (Group B) contained 11 more severe cases with both joints immobilized by scarring (type IV) 3 of whom had been tracheotomized.

4. RESULTS

4.1. Phoniatric results of Endoscopic Arytenoid Lateropexy in patients with Bilateral Vocal Cord Palsy (Tables III-IV)

The divergent results of voice parameters measured in the different study groups unequivocally support the need for this detailed categorization. In group I the aerodynamic and acoustic parameters may achieve or transcend the normal limits (Table III).

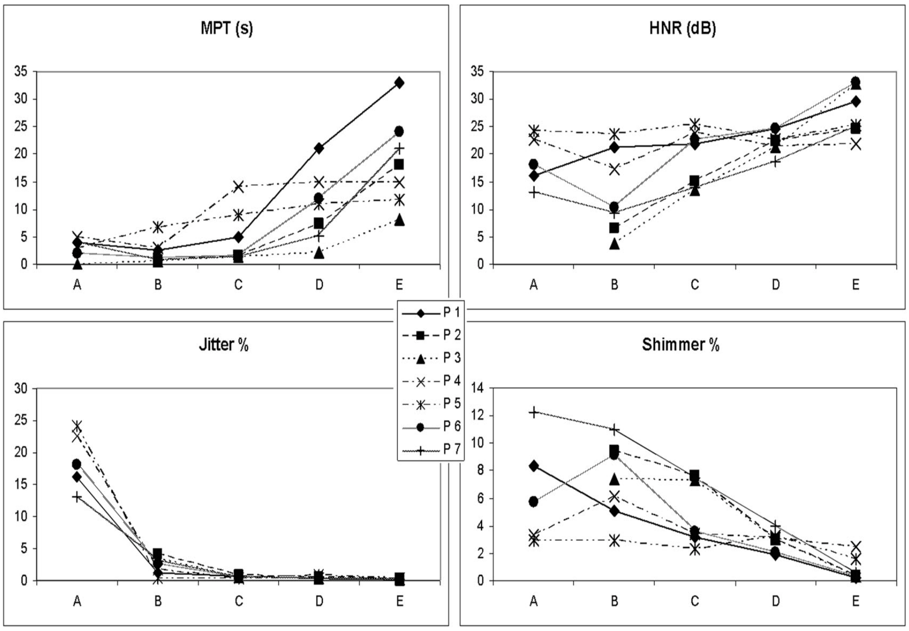

Figure 10: Voice parameters of BVCP patients with bilateral recovery A: before EAL (5 patients); B: within 1 week after EAL; C: after detection of the recovered movements; D: within 1 week after the removal of the suture; E: 1 year after releasing vocal cords (n=7; different symbols and line types represents each and every patients) relatively low MPT of Patient 3 is the consequence of severe COPD. MPT= maximum phonation time (normal range > 12 sec), HNR= harmonic to noise ratio (normal range > 20 dB), Jitt=Jitter (normal range < 1,04%), Shim=Shimmer (normal range < 3,81%), according to Praat software database

Their continuous improvement is demonstrated on Figure 10. This correlates well with the perceptual grading and with the self evaluation. However, the DSI and FDI revealed mild degree residual voice impairment with slightly decreased dynamic and frequency range. The videostroboscopy (Table IV) also demonstrated a fair motion recovery of arytenoid and the vocal cord system and the preservation of the vocal cord structures (Figure 11A and B).

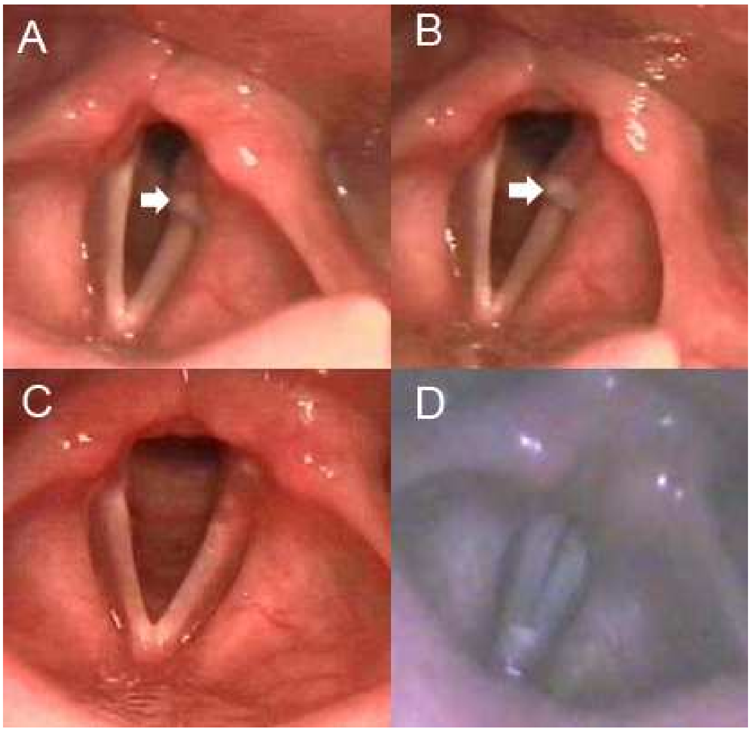

Figure 11: A. 32 year-old female with BVCP 3 month after EAL on the left side. (Arrows point to the fixating loops); B. The abduction recovery of the left arytenoid cartilage is easily detectable despite the laterofixing suture. The right vocal cord is still in paramedian position; C. The vocal cords recovered, the abduction is somewhat better on the left side (2 months after removal of the laterofixing suture); D. Stationary stroboscopic photography: the glottic closure and the voice completed (MPT=33s; Pitch=312Hz; HNR=29.6dB; Jitt=0.13%; Shim=0,26%; GRB=0,0,0; VHI=0, Clo:5, Reg:0 MW:0 , Sym:0

	Aero-dynamics	Acoustics				Perception 0-3				Dysphonia Indexes		Intensity	Frequency
	MPT (sec)	Pitch (Hz)	HNR (dB)	Jitt %	Shim %	G	R	B	VHI	FDI		Dynamic Range	FR in ST
I: patients with bilateral vocal cord recovery (n=7 ; 6 females and 1 male)													
Mean	18,16	252,20	27,62	0,24	0,51	0,71	0,43	0,14	3,67	0,31	1,76	21,33	14,88
SD (±)	7,62	86,11	3,96	0,11	0,47	0,45	0,49	0,35	3,86	0,26	1,28	4,20	3,64
II: patients with unilateral vocal cord recovery (n=6 ; 6 females)													
Mean	7,53	222,29	22,78	1,13	5,08	1,00	1,17	0,33	25,17	1,47	DSI	17,00	9,81
SD (±)	3,26	75,41	4,52	0,97	4,67	0,58	0,37	0,47	8,27	0,22	2,14	4,93	3,32
III: permanent BVCP patients with adduction movement regenerations (n=8 ; 7 females and 1 male)													
Mean	7,83	212,64	20,41	1,40	7,09	1,50	1,25	1,63	48,00	1,80	-2,73	10,00	4,57
SD (±)	5,10	78,30	4,54	1,25	4,56	0,50	0,66	0,70	21,00	0,42	1,68	5,55	1,86
IV: permanent BVCP patients with ventricular phonation (n=6 ; 5 females and 1 male)													
Mean	3,18	186,21	11,12	8,26	16,91	2,33	2,50	2,00	50,50	2,47	-10,16	8,83	2,94
SD (±)	1,49	38,93	4,34	6,56	6,62	0,47	0,50	0,82	8,88	0,19	8,22	3,02	2,59
V: permanent BVCP patients without ventricular phonation (n=5 ; 5 females)													
Mean	5,03	258,16	18,85	2,71	9,44	2,40	2,20	2,40	76,40	2,64	-3,49	9,00	7,30
SD (±)	3,15	102,15	8,01	1,94	5,65	0,49	0,75	0,49	20,47	0,37	2,67	3,52	1,68

Table III: Voice assessment of 32 BVCP patients underwent EAL

MPT= maximum phonation time (normal range > 12 sec), HNR= harmonic to noise ratio (normal range > 20 dB), Jitt=Jitter (normal range < 1,04%), Shim=Shimmer (normal range < 3,81%), according to Praat software database; G=grade, R= roughness, B= breathiness, from the GRBAS scale, VHI= voice handicap index, SD = standard deviation FDI=Friedrich's Dysphonia Index; 0 no deviance 1mild 2 moderate 3 severe deviance DSI = Disphonia Severity Index DSI = 0.13 x MPT + 0.0053 x F(0)-High - 0.26 x I-Low - 1.18 x Jitter (%) + 12.4. 5 good voicing; -5 bad voicing; DSI could reach values below -5 and above 5 as well. DR=Dynamic Range in dB; FR in ST=Frequency Range in Semitones; Different colors were used for better visualization; red=bad, purple =acceptable, gray =good, light blue=very good results

	Clo	Reg	Mw	Sym	SA
I: patients with bilateral vocal cord recovery (n=7 ; 6 females and 1 male)					
Mean	13,57	12,14	15,29	13,57	20,71
SD (±)	6,39	7,00	7,78	5,15	6,78
II: patients with unilateral vocal cord recovery (n=6 ; 6 females)					
Mean	23,33	42,50	28,33	49,17	28,33
SD (±)	7,99	10,70	6,87	6,07	11,79
III: permanent BVCP patients with adduction movement regenerations (n=8 ; 7 females and 1 male)					
Mean	48,13	45,00	41,25	47,50	46,88
SD (±)	13,68	16,58	16,15	13,92	13,45
IV: permanent BVCP patients with ventricular phonation (n=6 ; 5 females and 1 male)					
Mean	70,00	65,83	76,67	63,33	88,67
SD (±)	12,91	12,39	4,71	9,43	9,43
V: permanent BVCP patients without ventricular phonation (n=5 ; 5 females)					
Mean	86,00	70,00	64,00	72,00	19,00
SD (±)	10,20	22,80	13,56	11,66	9,17

Table IV. Videostorboscopic analysis of 32 BVCP patients underwent EAL

Stroboscopy rated on visual analogue scales each 100mm long: 0 no deviance, 100 severe deviances; Clo = closure, Reg = regularity, Mw = quality of mucosal wave, Sym = symmetry, SA = supraglottic hyperactivity, SD = standard deviation; Different colors were used for better visualization; red=bad, purple =acceptable, gray =good, light blue=very good results

Although in 6 of 8 cases the abduction was slightly impaired at the side of EAL, only a mild gap remained in phonation at the dorsal region which generally disappeared on forced voicing. The symmetry and the quality of the mucosal waves were practically normal (Figure 11 D).

In group II the acoustic parameters (Table III) approximated to normal values, but MPT, VRM, DSI, FDI moderately decreased. Perceptual analysis and VHI showed a mild to moderate dysphonia. The endoscopic examinations (Table IV) justified the medialization of the released vocal cords, which allowed an improved phonation closure with moderately increased supraglottic activity. In 2 larynges only mild dorsal gaps were observed and in 4 other cases moderate longitudinal closure gaps. Good mucosal waves could be detected on both sides with slight to moderate asymmetry in all cases. In the latter 4 patients vocal cord medialization was performed later.

In group III clear voluntary adductions were observed during phonation with remarkable supraglottic activity. This allowed an acceptable, relatively mild dorsal or longitudinal phonatory closure gap of the glottis with acceptable mucosal waves (Figure 12 B).

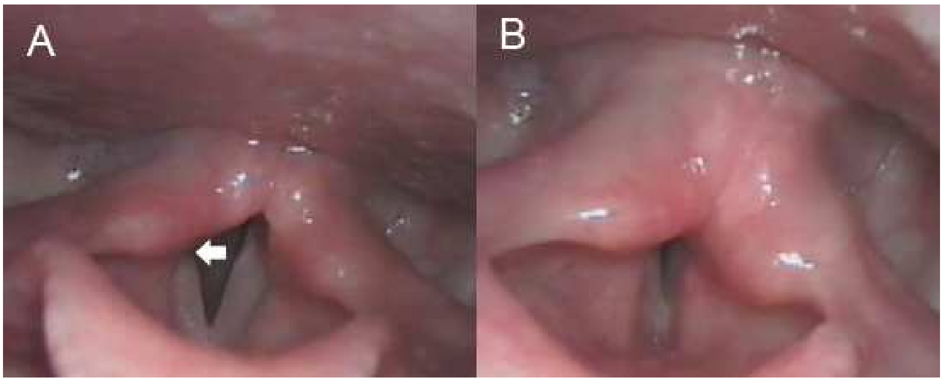

Figure 12:A. BVCP of a 24 year-old female 3 years after EAL on the right side. The left arytenoid cartilage is in abduction (arrow points to the fixating loops); B. Acceptable phonation closure can be observed due to adduction recovery on the left side (MPT=6.8s; Pitch=263Hz; HNR=21.2dB; Jitt=1.53%; Shim=6,8%; GRB=1,1,1; VHI=32 GRB=0,0,0; Clo:40, Reg:40 MW:30 , Sym:40, SA:55,

This explains the only mild to moderate dysphonia in this group, which was characterized with generally slightly breathy but fatigued voice. The acoustic parameters also approximated to the normal values, however, the MPT, VRM, DSI, FDI scales demonstrated remarkably decreased quality. The VHI demonstrated moderate loss of function as well. (Table III)

In group IV extreme supraglottic activities were observed allowing a dominant approximation of the laryngeal structures especially between the ventricular folds (dominantly ventricular phonation), which explains the high grade irregularity in the phoniatric parameters. The perceptual analysis and the VRM, DSI, FDI also measured severe dysphonia. In spite of this as the VHI shows the patients find their voice to be acceptable for the everyday communication.

In group V although poor laryngeal activity was observed during a forced attempt of phonation notably there was no detectable significant phonation contact between the laryngeal tissues. The objective voice parameters well correlated to the perceptual assessment; the voices were seriously breathy and hoarse. This well correlates with the DSI, FDI.

We could not find significant alteration in the pitch compared to the normal values but many of the patients in group II and III reported on a mild increase in this parameter compared to their voice before the onset of RLN palsy.

4.2. Phoniatric results of Endoscopic Arytenoid Lateropexy in patients with Posterior Glottic Stenosis

In all patients, the ETGI successfully enabled the creation of or fixating loops at the effective laryngeal positions. In 20 of the 21 patients, breathing ability significantly improved immediately after surgery. In one male with ongoing chemo-radiotherapy due to an upper-esophageal cancer a temporary and a permanent tracheostomy had to be performed. Except for this case improved peak inspiratory flow (PIF) in the early post-operative period indicated the immediate efficacy of the procedure. One year after the operation the PIF values almost doubled demonstrating the long-term reliability of the intervention.

Mechanical fixations Posterior glottic stenoses (n= 21; female/male=9/12)				
	Age (years)	Preop.*	PIF (l/s) Postop.†	Final results^
Mean	43	1.77	2.72	4.04
Min./max.	15/74	1.25/2.37	1.75/4.37	3.12/5.62
SD	±15.65	±0.45	±0.83	±0.98

Table V.
*The normative PIF value[127] in mixed-gender, healthy, young population is 4 L/s. In cases of unilateral VCP the PIF is about 70% to 80% of the normative value.[128] These facts suggest that the postoperative PIF of these older BVCP patients approximates to the theoretical maximum value, therefore the glottic configuration of EAL is similar to a unilateral VCP patient in inspiration. *One patient with cannula, two intubated patients, and three patients with severe suffocation were not measured. †One patients with cannula and two patients with severe suffocation were not measured. ^At least 1 year after EAL (patient with advanced esophageal tumor died in the 6th month).*
PIF= peak inspiratory flow; SD = standard deviation.

In Table VI we can see the long term (one year) phoniatric outcome of the different objective and subjective phoniatric values, according to the degree of the scar formation (Bogdasarian-Olson classification)

We can clearly confirm, that Group A has significantly better results than Group B. In this group all the subjective and objective measurements confirm, that the voice quality is about the same as after a unilateral palsy, which is normally a slightly impaired voice, and do not cause any handicap in the everyday communication.

In Group B the results are far worse, and in spite of the increased noise component, and decreased functional values, (frequency range, dynamic range) our results approximates our other groups treated with arytenoid lateropexy in cases of permanent bilateral vocal cord palsy. Table III Table VI.

4.3 Comparing the suggested Standard Phoniatric Panel parameters to the each other and to the complex measurement indexes by statistical factor analysis

Factor analysis is a statistical method used to describe variability among observed variables in terms of a potentially lower number of unobserved variables called factors. In other words, it is possible, for example, that variations in three or four observed variables mainly reflect the variations in a single unobserved variable, or in a reduced number of unobserved variables.

With the use of statistiXL 1.8 www.statistixl.com freeware data analysis package, that runs as an add-in to Microsoft's Excel™ we performed Factor Analysis among the different measurements used in this thesis for the patients with different types of bilateral vocal cord immobility. The correlation is good if the value of the number is near 1, or near -1. The Correlation matrix can be seen on Table V. For the sake of the homogeneity of the examined group this statistical analysis was performed on only on vocal cord immobility group.

Evaluating the factor analysis we can confirm, that FDI has good correlation with MPT, VHI, DR, FR, and the stroboscopic examinations. DSI has good correlation with the perturbation measurements. Of course the stroboscopic examination among each other and the perception (GRB scale) among each other has the highest correlation. DR correlates with closing, and regularity, and FR with mucosal wave and symmetry in our study group but these statements needs further investigations. VHI has a strict correlation with nearly all examinations except the perturbation measurements.

	Aero-dynamics	Acoustics				Perception 0-3				Dysphonia Indexes		Intensity	Frequency
	MPT (sec)	Pitch (Hz)	HNR (dB)	Jitt %	Shim %	G	R	B	VHI	FDI	DSI	Dynamic Range	FR in ST
I: Group A; patients with Bogd-Ols grade I-III (n=9 ; 6 females and 3 male)													
Mean	8,90	193,2	18,72	1,03	5,47	0,71	1,14	1,14	31,71	1,66	-1,88	15,13	19,00
SD (±)	5,54	51,61	4,51	1,36	3,02	0,49	0,38	1,07	21,59	0,26	1,87	5,26	4,07
II: Group B; patients with severe scar formation Bogd-Ols grade IV (n=11 ; 3 females and 8 males)													
Mean	4,17	134,6	10,98	1,61	5,89	1,67	1,33	1,83	50,17	2,43	-2,50	15,83	7,17
SD (±)	2,25	19,56	5,08	1,04	4,77	0,52	0,52	0,75	15,26	0,21	2,19	7,51	3,98
III: Group A+B; all patients with PGS Bogd-Ols I-IV (n=20; 9 females and 11 males)													
Mean	6,72	171,9	15,15	1,30	5,67	1,15	1,23	1,46	40,23	2,02	-2,17	15,43	13,54
SD (±)	4,85	50,84	6,09	1,21	3,75	0,69	0,44	0,97	21,05	0,45	2,05	6,44	7,14
To compare with all BVCP treated with EAL (n=32; 29 females and 3 males)													
Mean	8,72	225,3	20,44	2,59	7,48	1,53	1,44	1,25	40,06	1,67	-3,11	13,50	14,59
SD (±)	7,14	82,41	7,41	4,15	7,18	0,83	0,93	1,06	27,61	0,88	5,52	6,86	6,16
Permanent palsy BVCP 19 patients treated with EAL (17 females 2 males)													
Mean	5,62	216,3	17,06	3,91	10,81	2,00	1,89	1,95	56,26	2,23	-5,28	9,37	10,89
SD (±)	4,28	80,99	6,94	4,93	7,01	0,65	0,85	0,76	21,61	0,51	5,96	4,40	2,85
Harnisch et al. [21] : 10 patients with mainly transverse cordotomy (8 females and 2 males)													
Mean	5,02	202,6	2,91*	5,02	24,93	2,00	1,00	2,00	55,00	2,16	-5,60	28,60	16,27
SD (±)	5,46	39,60	0,54*	5,46	9,47	1,00	1,00	1,00	19,00	0,50	6,27	9,34	5,93

Table VI: Voice assessment of 20 PGS patients underwent EAL

MPT= maximum phonation time (normal range > 12 sec), HNR= harmonic to noise ratio (normal range > 20 dB)(:noise component instead of HNR) ; Jitt=Jitter (normal range < 1,04%), Shim=Shimmer (normal range < 3,81%), according to Praat software database; G=grade, R= roughness, B= breathiness, from the GRBAS scale, VHI= voice handicap index, SD = standard deviation FDI=Friedrich's Dysphonia Index; 0 no deviance 1mild 2 moderate 3 severe deviance DSI = Disphonia Severity Index DSI = 0.13 x MPT + 0.0053 x F(0)-High - 0.26 x I-Low - 1.18 x Jitter (%) + 12.4. 5 good voicing; -5 bad voicing; DSI could reach values below -5 and above 5 as well; Different colors were used for better visualization; red=bad, purple =acceptable, gray =good, light blue=very good* results

Table V: Correlation matrix of different measurements. Detailed explanations see in abbreviation part.
Good correlation in green if value is below -0,6 or above 0,6

Correlation Matrix

	MPT	Pitch	HNR	Jitter %	Shimmer %	FR	DR	G	R	B	VHI	Clo	Reg	Mv	Sym	SA	FDI	DSI
MPT	1,000	0,154	0,516	-0,432	-0,628	0,637	-0,518	-0,603	-0,767	-0,551	-0,589	-0,635	-0,665	-0,676	-0,728	-0,421	-0,826	0,511
Pitch	0,154	1,000	0,442	-0,004	-0,027	0,199	0,069	-0,250	-0,218	-0,096	-0,100	-0,065	-0,098	-0,359	-0,173	-0,223	-0,112	0,102
HNR	0,516	0,442	1,000	-0,367	-0,634	0,571	-0,414	-0,537	-0,584	-0,477	-0,600	-0,562	-0,577	-0,746	-0,622	-0,515	-0,612	0,457
Jitter %	-0,432	-0,004	-0,367	1,000	0,858	-0,449	0,285	0,377	0,432	0,451	0,336	0,521	0,480	0,545	0,478	0,533	0,434	-0,950
Shimmer %	-0,628	-0,027	-0,634	0,858	1,000	-0,634	0,460	0,553	0,624	0,592	0,587	0,698	0,672	0,721	0,680	0,572	0,675	-0,842
FR	0,637	0,199	0,571	-0,449	-0,634	1,000	-0,603	-0,631	-0,626	-0,701	-0,679	-0,680	-0,616	-0,753	-0,715	-0,588	-0,804	0,490
DR	-0,518	0,069	-0,414	0,285	0,460	-0,603	1,000	0,662	0,615	0,759	0,864	0,816	0,678	0,649	0,747	0,134	0,833	-0,361
G	-0,603	-0,250	-0,537	0,377	0,553	-0,631	0,662	1,000	0,871	0,667	0,805	0,832	0,764	0,852	0,753	0,453	0,815	-0,399
R	-0,767	-0,218	-0,584	0,432	0,624	-0,626	0,615	0,871	1,000	0,616	0,745	0,760	0,766	0,831	0,746	0,505	0,875	-0,432
B	-0,551	-0,096	-0,477	0,451	0,592	-0,701	0,759	0,667	0,616	1,000	0,823	0,867	0,704	0,788	0,754	0,341	0,777	-0,485
VHI	-0,589	-0,100	-0,600	0,336	0,587	-0,679	0,864	0,805	0,745	0,823	1,000	0,889	0,835	0,825	0,869	0,205	0,881	-0,397
Clo	-0,635	-0,065	-0,562	0,521	0,698	-0,680	0,816	0,832	0,760	0,867	0,889	1,000	0,840	0,863	0,827	0,359	0,862	-0,561
Reg	-0,665	-0,098	-0,577	0,480	0,672	-0,616	0,678	0,764	0,766	0,704	0,835	0,840	1,000	0,794	0,892	0,336	0,814	-0,560
Mv	-0,676	-0,359	-0,746	0,545	0,721	-0,753	0,649	0,852	0,831	0,788	0,825	0,863	0,794	1,000	0,847	0,568	0,848	-0,581
Sym	-0,728	-0,173	-0,622	0,478	0,680	-0,715	0,747	0,753	0,746	0,754	0,869	0,827	0,892	0,847	1,000	0,314	0,881	-0,570
SA	-0,421	-0,223	-0,515	0,533	0,572	-0,588	0,134	0,453	0,505	0,341	0,205	0,359	0,336	0,568	0,314	1,000	0,457	-0,509
FDI	-0,826	-0,112	-0,612	0,434	0,675	-0,804	0,833	0,815	0,875	0,777	0,881	0,862	0,814	0,848	0,881	0,457	1,000	-0,493
DSI	0,511	0,102	0,457	-0,950	-0,842	0,490	-0,361	-0,399	-0,432	-0,485	-0,397	-0,561	-0,560	-0,581	-0,570	-0,509	-0,493	1,000

5. DISCUSSION

5.1. Phoniatric results of bilateral vocal cord palsy treated by Endoscopic Arytenoid lateropexy

The pathophysiology of the vocal cord paralysis is not completely understood despite the numerous meticulous animal and human studies [47, 129]. The intraoperative stretching, thermal damage, etc. often causes only axono- or neuropraxy which explains the frequently reported laryngeal function regeneration (40-86%) [20, 37], nevertheless the exact definition of recovery is rarely mentioned precisely in these papers [21, 25, 26]. As the studies of this subject [47, 129] describe, the regeneration mechanism is complex and variable, and most of the muscles generally regain more or less reinnervation following RLN injury. These “reinnervation” processes may be completed in several months after the onset of paralysis. The final result of regeneration generally ranges from the complete or almost complete recovery of the vocal cords to poorer outcomes with different types of synkinesises which basically determinates the retained voice. Hence, Crumley suggested using the terms of “laryngeal vocal cord mobility impairment” instead of “vocal cord paralysis” to these conditions[47]. This points out that the phoniatric assessment of a glottis enlarging procedures requires a detailed categorization of the patients according to the outcome of their regeneration process.

In our cases of *complete recovery* the vocal cord functions regained within few months after the fixating suture removal. The previously lateralized cricoarytenoid joint generally had mild movement limitation compared to the contralateral side but it must be considered that the EAL was always performed on the side were the nerve damage was presumed more severe [30]. In relation with the slightly impaired phoniatric parameters the following facts should be also considered: those were also found similarly impaired even after uneventful strumectomies [130]; and the fine tuning mechanism probably does not regenerate perfectly after the recurrent nerve injury. In patients with unilateral vocal cord recovery (Group II) the previously lateralized vocal cords re-medialized after the suture removal, and their phoniatric parameters well correlated with the result of the untreated unilateral vocal cord palsies group [10]. This data supports the reversibility of EAL to a large extent.

It appears that aberrant and poorly functioning reinnervation rather than denervation, is the most common laryngeal problem in patients following *permanent* RLN injury [47]. Moreover, the connections, which can individually be found in human larynges [54] (whose effect is normally masked by the intact dominant innervation system) or develop pathologically during the healing process [47] between the superior and inferior laryngeal nerve network, may also have some additional motor effect (mainly on the supraglottic or interarytenoid laryngeal muscles) [54]. The fibers of the pharyngeal muscles attached to the arytenoid cartilage may also play a role in this phenomenon. Thus, preservation of the intrinsic laryngeal muscles as much as possible during the surgical procedures seems to be unambiguous even in cases of “permanent” paralyses because they may play role in the tension and the active residual motions of the vocal cords. The EAL ensures a stable, properly wide glottis this way by a simple and fast endoscopic insertion of a double loop around the arytenoid cartilage by the ETGI [125, 131] , approximated to its abducted position [124].

In our series Group III and IV contain the most of the patients with permanent paralyses (14 of 19 patients) in which the wide glottis was combined with socially acceptable voice, especially in group III. We observed active adduction which provided phonatory closure by overcompensation of the non lateralized cords or between the ventricular folds. This phenomenon is supported by Woodson’s recent animal experiments which confirmed that the preferential reinnervation of adductor muscles may account for a medial position of the paralyzed vocal cords and the increasing activity of supraglottic muscles [129]. This residual (or synkinetic) activity on the non lateralized side can be more notable where the EAL ensures the almost complete abducted position of the operated side of larynx, than glottis enlarging procedures which leave the arytenoid in a rather inspiratory position (Figure 9 A, B). Group III also proves that the tensed and straightened vocal cords by EAL despite their more lateral position can ensure a more favorable situation for phonation than the preoperative medial but bowed and more or less flaccid condition. Finally, the above detailed residual muscle activity especially in the interarytenoid region may facilitate the approximation of the vocal processes to complete the closure despite the different vocal cord levels achieved postoperatively.

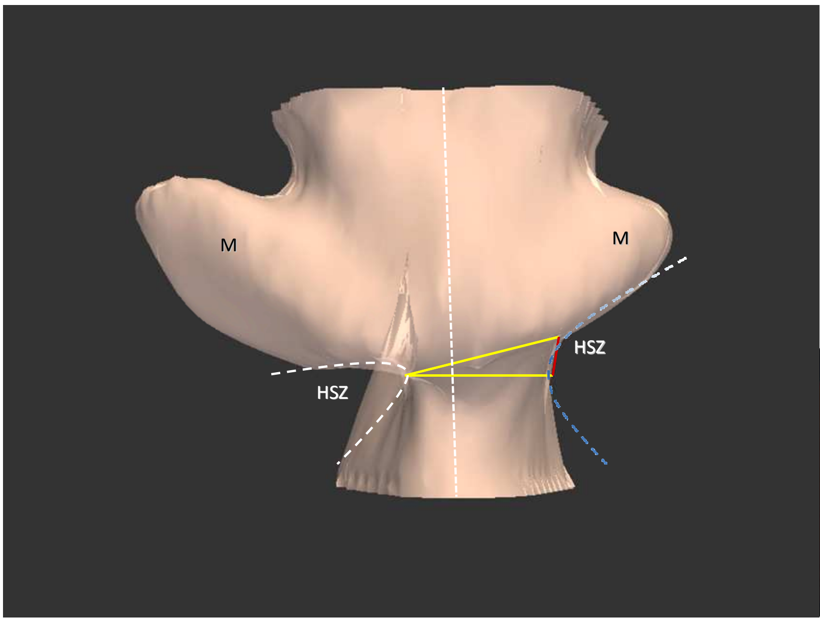

Figure 13: Three dimensional CT reconstruction of the laryngeal structures (air column) after EAL. M=Morgagni’s ventricle HSZ=vocal fold. We can observe the different levels of the vocal folds in case of lateralization the arytenoid cartilage to its normal abducted position.Right endoscopic picture of the same patient.

(Figure 13). These allowed the patients a fairly good, more-or-less breathy voice with good acoustic parameters in group III. The dynamic and frequency range were decreased, however the 5-7 semitones satisfies the everyday communication requirements [132]. High grade irregularity of acoustic parameters and poor perceptual results were found in Group IV, but the patients self evaluation showed acceptable communication ability with this limited voicing. Only those in Group V had a severe dysphonia with remarkably decreased communication ability. Three of them were elderly patients with a poor overall health condition, which alludes to the necessity of good respiratory condition in spite of the impaired phonation described above. In regard to the other two cases a complete recurrent nerve trans-section should be presumed. These unpleasant phonatory situations might be improved by appropriately guided speech therapy but a reoperation can be considered too. A repeated EAL might be suggested after the fixating suture removal; in this case the arytenoid can be placed into a more medial position. Other types of glottis widening procedures also can be envisaged, however in these cases with negligible residual activity, reoperations probably would not give satisfactory voice improvement and they may lead to breathing impairment.

	Aero-dynamics	Acoustics				Perception 0-3				Dysphonia Indexes		Intensity	Frequency	
	MPT (sec)	Pitch (Hz)	HNR (dB)	Jitt %	Shim %	G	R	B	VHI	FDI	DSI	Dynamic Range	FR in ST	PIF
Pruzewicz et al.[26] : 13 patients with arytenoidectomy n=13 (12 females 1 male) SD (±) not published														
Mean		238,00	1-11,4	2,30	7,00									
Dursun et al. [25] : 22 patients with transverse cordotomy (female/male not published)														
Mean	7,30	184,00	12,45	1,13	7,00									
SD (±)	1,50	55,00	3,00	1,00	3,00									
Harnisch et al. [21] : 10 patients with mainly transverse cordotomy (8 females and 2 males)														
Mean	5,02	202,60	2,91*	5,02	24,93	2,00	1,00	2,00	55,00	2,16	-5,60	28,60	16,27	1,61
SD (±)	5,46	39,60	0,54*	5,46	9,47	1,00	1,00	1,00	19,00	0,50	6,27	9,34	5,93	0,4
All patients 32 patients (29 females, 3 males)														
Mean	8,72	225,26	20,44	2,59	7,48	1,53	1,44	1,25	40,06	1,67	-3,11	13,50	14,59	2,43
SD (±)	7,14	82,41	7,41	4,15	7,18	0,83	0,93	1,06	27,61	0,88	5,52	6,86	6,16	0,73
Permanent palsy group III, IV, V 19 patients (17 females 2 males)														
Mean	5,62	216,27	17,06	3,91	10,81	2,00	1,89	1,95	56,26	2,23	-5,28	9,37	10,89	2,24
SD (±)	4,28	80,99	6,94	4,93	7,01	0,65	0,85	0,76	21,61	0,51	5,96	4,40	2,85	0,68

Table VII:

Table VII: Comparison of phoniatric parameters published in other studies to our results. See legend of Table III. PIF= Peak Inspiratory Flow, (:noise component instead of HNR)*

The different colors for the better visualization; red=bad, purple =acceptable, gray =good, light blue=very good results

Comparing our data to the few studies presented in the international literature [21, 25, 26] (Table VII) about the phoniatric outcome of glottis enlarging procedures, even after transverse cordotomy, which is considered to be one of the most voice preserving intervention[24], a significant postoperative voice deterioration can be expected compared to the normal voicing.

Moreover these studies do not distinguish between the different regeneration levels, which were found in the present study. Comparing the average results of those studies to our all patients' ones the EAL provide a more favorable vocal outcome than the transverse cordotomy. If we take only our permanent BVCP cases (Group III-V) the average results are approximately the same, but in case of EAL the postoperative respiratory parameters are remarkably better.

5.2. Phoniatric results of endoscopis arytenoid lateropexy in Posterior Glottic Senoses

Until the end of the last century the endoscopic procedures were suggested only for the treatment of low grade PGS. [36, 70] These interventions mainly based on the resection of the glottic structures (arytenoid cartilage, vocal cord) thus they caused drastic irreversible impairment in laryngeal function, however their outcome (especially in cases of high grade PGS) were poor because of the primarily damaged posterior commissure structures. The one of the main goals of our procedure was to improve the airway without an extended resection of the glottic tissues thus preserved the laryngeal function (e.g. voice quality) as much as possible.

Our cases proves that once laterofixation was abolished, laryngeal motion became physiologic and voice quality got close to the patients' original voice in cases of stenoses not destroying the joint structure. This series on a large number of patient supports clinical observations, that temporary laterofixation in the treatment of PGS can be done without causing lasting damage to laryngeal movement, and phonatory handicaps. Thus this procedure is a reliable treatment in the treatment of PGS for preventing suffocation. Our experience is that laryngeal movement and voice production improved in many cases when the intracapsular scarry fixation had to be transected with the endolaryngeal scythe. One explanation for this may be that the joint surfaces are partially preserved or that a pseudojoint develops which more or less enables motion. Mitomycin-C may promote this process by reducing intracapsular scarring. Somewhat better movement regeneration was observed in our patients treated thus, but proving this needs further examinations.

Our phoniatric results well support these clinical observations; in case of lower grade stenoses the parameters were close to or transcended the normal limits. In cases of high grade stenoses the parameters showed a wider variance. However, the patients could be decanulated or their breathing remarkably improved, the phonation remained impaired in many cases in spite of the mobilization of the CAJ. In 5 out of 11 patients (Group B) the overall voice quality converged to the lower limits of the normal parameters, in 3 cases it was socially acceptable and only in 2 patients had severely impaired. This points out that the group of "bilateral joint fixation" contains patients with different scar involvement of their CAJ. In those cases where the post-operative voice showed nearly normal values we should consider an only partial original scar involvement in contrast with the patients in which the arytenoid motions did not improved. This suggests a clinically important subdivision of the Bogdassarian-Olson IV category; however, it requires further examinations as well. The results support our theory that this intervention from the view of phonation high grade reversible in the majority of the cases. Comparing our results with other interventions used in PGS is not available in the international literature. The lack of these examinations probably does not mean only the lack of the interest of the authors.

5.3 Discussion of the usage of FDI, DSI and the Standard Voice Panel suggested in the everyday Practice

We can conclude about the complex dysphonia indexes, that both FDI, and DSI are very useful tools for the evaluation of the voice quality of our patients in one linear, numeric scale. FDI has higher correlation with the perceptual scale, MPT and with the frequency and dynamic range measurements. Despite the DSI was constructed to measure the overall voice quality with the help of objective measurements, it has strict correlation only with the perturbation measurements as Jitter and Shimmer in our patient group. FDI and DSI can help us to control our work and compare our results with the international literature, moreover help to find the exact role of the nowadays popular complex indexes in the evaluation of the human voice impairments.

VHI has a good correlation with nearly all examinations, so this test is a useful tool for the evaluation of our patients' overall voice quality. These data gained in our homogenous population of a surgically treated BVCI patients well supports the recent observations[133]

Factor analysis also shows, that the extended examination protocol do not contains extremely new information comparing to the Standard Voice Panel which is a time and resources consuming method containing the objective and subjective measurements also.

6. CONCLUSIONS and NEW RESULTS

6.1 Conclusion of the phoniatric results with the use of EAL

Bilateral vocal cord impairment is not a static condition, and its outcome shows within several months after the onset of RLN injury. The late phoniatric results of EAL justifies that this reversible procedure provides excellent outcome in temporary BVCP. The postoperative, residual voice in permanent paralysis is generally considered to be weak; inversely proportional to the adequacy of the airway achieved by the ordinary glottis widening procedures. In contrast, an acceptable voice with a stable and adequate airway could be achieved by EAL with the preservation of fine laryngeal structure in most cases of permanent paralyses. Taken together this intervention may provide a base of a less complex, dynamic alternative concept for the BVCP treatment.

6.2 Conclusion of the phoniatric results in PGS with the use of EAL

In isolated cases of PGS, an endoscopic arytenoid lateropexy after appropriate cricoarytenoid joint mobilization can be carried out with the use of ETGI performing EAL, without performing or sustaining a tracheostomy. This minimally invasive laryngeal function-preserving method ensures an uncompromised full recovery in cases of lesser stenoses, but even in severe stenoses may be applied with results that equal or transcend those of external procedures besides the functional airway flow, also from the view of phoniatry.

6.3 Conclusion of the usage of the Standard Voice Panel suggested in the everyday Practice

We can conclude, that using our “Standard Voice Panel” is a simple, time and resources consuming method for the everyday practice, and the evaluation extended with dynamic range[116], frequency range[116], and complex dysphonia indexes (DSI[115] and FDI[10]) is available for scientific use. Factor analysis revealed the connections of the examined voice parameters in between the Standard Voice Panel, moreover, the relation of these parameters with the DSI, FDI, DR, FR.

6.4 New results

- We have introduced a suitable complex protocol containing different subjective and objective measurements in Hungary [122] which fits to the guidelines announced by European Laryngological Society.
- we introduced an objective perturbation measurements for the phoniatric evaluation of laryngeal surgical methods in Hungary and a widely accepted subjective self evaluation test (VHI)

- With the use of the Standard Voice Panel we confirmed that the EAL is a mostly reversible procedure in cases of full recurrent nerve regeneration in BVCP.
- In cases of partial nerve regeneration the EAL provides better phoniatric results than the traditional glottic enlarging methods based on tissue resection in BVCP patients.
- In PGS we performed a phoniatric evaluation of the applied surgical procedure. The results show that the use of EAL provides good voicing, besides the good functional result in breathing. The opening of the CAJ should not lead to negative effect on phonation.
- Our phoniatric results in PGS support our clinical observation that the sub-categorization of Bogdassarian-Olson group IV patients is needed to predict the functional outcome of the surgical procedures.
- We showed that in a homogenous group surgically treated BVCP patients, there is a statistical correlation between the different phoniatric parameters
- With the result of factor analysis we demonstrated the usefulness of the Hungarian version of VHI in the evaluation of the voice quality of our phoniatric patients.

7. ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to Prof. Jenő Czigner former head of the department who introduced me to the clinical work.

I wish to express my grateful thank and respect to Prof. József Jóri, the present director of the department, for guiding me with his important advices and instructions, both regarding my scientific and clinical work and who gave me the opportunity to work in the Clinic of Otolaryngology in the laryngological research team.

My special thanks to my supervisor and tutor Dr. habil Ph.D László Rovó the head of our research team in laryngology for his continuous scientific help during this study

I would like to express to my sincere gratitude to dr. József G. Kiss and Alice Szamosközi for their cooperation, technical help in the studies and in evaluation of the results.

I am deeply indepted to my other colleagues, especially Dr László Szakács, Dr. Shahram Madani and Dr. Balázs Sztanó, for their cooperative daily work.

Last but not least, very special thanks to my family and to my friends, for their support and their patient for me in my efforts to complete this thesis.

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APPENDIX 1

VHI Kérdőív

Dátum:

Név:

Foglalkozás:

Diagnózis:

Jelölje meg azt a választ, amely megmutatja, milyen gyakran fordulnak elő a következő állítások Önnel!

Válaszok: 0 = soha, 1 = ritkán, 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

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