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SURGICAL ANATOMICAL ASPECT OF CRICOARYTENOID JOINT

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INTRODUCTION AND AIMS OF THE THESIS

The treatment of laryngeal, laryngotracheal stenoses is considered one of the most difficult fields of laryngology. While in the earliest reports, diphteria, tuberculosis, syphilis, or the treatment thereof were the major etiological factors, nowadays the current medical treatments have significantly reduced the incidence of these diseases and their sequelae. There have also been several recorded cases of congenital stenosis from the end of the 19th Century. However more importantly from the 1900 onwards, the effect of direct laryngeal trauma to the larynx has been recognized as the most common factor, including most frequently the traumatic lesions of the laryngeal nerves, laryngeal intubation or hasty tracheotomy and direct trauma. Unfortunately, the development and the increasing number of medical interventions induced an increasing number of iatrogenic laryngeal stenosis in the last decades.

Glottic stenoses are a well-defined part of this laryngeal disorders. Nowadays, mechanical or paralytic mobility disorders of the vocal cords developed after long-term intubation or after surgical procedures in the area of the laryngeal nerves give the highest percentage of them. The incidence of vocal cord paralysis after thyroid surgery was recently reported to be 0.5- 3.2 % depending on the skill of the surgeon or the applied surgical technique, but in case of reoperation or malignancy this ratio may increase up to 10 %. The diagnosis of bilateral nerve injury causing acute respiratory failure is fortunately rare, less than 1 %. Nevertheless, unilateral, and sometimes probably the bilateral vocal cord paralysis may be more common than is thought; because the symptoms may resolve before an individual seeks medical attention or if the suffocation presents only on effort they may be overlooked during examinations. Considering these facts we can conclude that vocal cord paralysis is the one of the most common and most feared complications of thyroid surgery even nowadays, and the almost 7 000 thyroid surgeries performed in a year may lead to hundreds of vocal cord disorders according to the data of the Hungarian Health Care Insurance.

The other common etiological factor of glottic stenosis is the pseudoparalysis of the vocal cords. This means the mechanical block of the vocal cord movement by scar formation in the posterior laryngeal commissure usually with intact innervation. This presents most commonly after prolonged intubation in intensive care units. Incidence ranges from 1-10% depending on the disease, the duration of intubation, the size of the tube, the presence of local infection etc. The number of intensive care patients significantly increases in every year in

Hungary. While this number was approximately 48 000 in 1998, by in 2001 it was already more than 65 000. This means that more or less severe posterior glottic stenosis can be observed in several hundred patients a year.

While, in case of bilateral vocal cord immobility suffocation generally necessitates urgent diagnosis and treatment, unilateral vocal cord immobility generally has no such terrifying symptoms. The most common problem in this case is the considerable worsening of voice quality. However, this gets a significant importance nowadays from the view of quality of life, especially in case of a professional voice-user. The other not so common, but more dangerous symptom is aspiration, especially, when the paralysis associates with the lesion of sensorial innervation (vagal lesion). Hence, the solution of these problems has become one of the most studied problems of laryngology in the last decades.

The new diagnostic tools, as CT, MRI, electromyography, endoscopic methods can establish proper preoperative diagnosis. The new surgical instruments, as surgical lasers, the new type of laryngoscopes, Lichtenberger's needle carrier etc. ensure the endoscopic treatment of most laryngeal disorders instead of the classic external surgical techniques obviating the need for external incisions and minimizing the amount of tissue disruption. This trend is strongly supported by the new anesthesiological methods: by the different types of JET-ventilation, total intravenous narcosis, controlled myorelaxation etc. The effort to refine the traditional techniques with new possibilities provided by the new equipments, development of new therapeutic strategies provided by these new surgical techniques well refers to the modern, minimally invasive view of surgery. Especially, in these generally iatrogenic disorders, the surgeon has increased responsibility to minimize the patients' further somatic and psychical trauma.

Since 1986 the laryngeal disorders have became the mean research field of our clinic. The " Reconstructive and organ sparing surgery, clinical and experimental research in the oto-rhino-laryngology, head and neck surgery" is the officially accredited subprogram of the "Clinical and experimental research for reconstructive and organ sparing" PHD program of the Faculty of General Medicine, University of Szeged. I have involved in the research team of Professor ***Jenő Czigner*** and Professor ***József Jóri*** since 1990. My interesting field was the study and treatment of the motional disorders and glottic stenosis of the larynx.

The main structural elements and the function of the larynx were recognized in times of antiquity, nevertheless, the fine anatomical details, such as the role of the laryngeal nerves in sensorial and motoric innervation of the larynx, the exact activity of the laryngeal muscles are extensively studied questions even nowadays. More-or-less controversial results and theories, even in case of fundamental physiological mechanisms, require further examinations to clarify these clinically important questions. In our first studies we examined the presence and the debated role of the *intralaryngeal neural connections* between the main laryngeal nerves. One aspect of this study was to examine the motoric activity of one of these anastomoses in order to find a new explanation for the pathophysiological incidents in the paralyzed vocal cords and the possible role of this anastomosis in the phoniatrical and surgical rehabilitation.

In our other theoretical study we analyzed the debated mechanism of the *cricoarytenoid joint*. This joint provides the framework of the main muscles and ligaments taking part in the vocal cord motion, thus, in a complex unit with the vocal cord, determinates essentially the normal and pathological vocal cord movement. In spite of this, its examination and the assessment of the result has not gained appropriate interest so far, and generally remained in theoretical field in the literature. It is obvious, that perfect understanding of its mechanisms is basically required in the search of accurate, new and more physiological treatment modalities. Thus, over the theoretical interest these questions have gained real practical meaning and formed the base of the development of internationally accepted, minimally invasive treatment concepts for the various types of bilateral and unilateral vocal cord paralyses by the adaptation and modification of the previous surgical techniques.

In this thesis I extract five topics of our work-team (two theoretical and three clinical), in which the theoretical background and the achieved results of our concepts are explained. The aims of the thesis are the following.

Theoretical part

Study of Galen's anastomosis (ansa Galeni):

The role of the internal branch of the superior laryngeal nerve (SLN) in the motoric innervation of the intrinsic laryngeal muscles is a returning question throughout the history of laryngology. This control are supposed by trough anatomical connections to the recurrent laryngeal nerves (RLN). We examined the anatomical details and the physiological aspects of one of this connections: the ansa Galeni (AG). The aim of our study:

- to justify the presence an invariant intralaryngeal anastomosis between the superior and recurrent laryngeal nerves, by animal and human anatomical dissections.
- the examination of the surgical-anatomical details of this anastomosis

- to examine the possible role of this anastomosis in the laryngeal physiology by laryngo-neuromyography: a: to identify direct motoric activity to the internal laryngeal muscles; b: to clarify the role of the sensorial fibers of the anastomosis.
- to take attention to the possible clinical importance of this anastomosis

Analysis of cricoarytenoid joint movement by picture digitalization technique

The exact mechanism of movement of the cricoarytenoid joint is still a matter of debate today. Present theories suppose the separate or combined presence of three main forms of movement: rotation around the axis which goes through the joint and is more or less perpendicular to the top view plane; the medio-lateral gliding on the surface of the joint additionally a rotation around the axis in the plane of the joint surface, thus rocking forward or backward. The aim of our study was to define the cricoarytenoid joint movement by our movement averaging technique on 100 normal human larynxes. Processing digitally the endoscopic images, analyzing and averaging the shots, we can count the changing positions of the arytenoids cartilage during ab- and adduction. Adding the results to the findings of modern anatomical examinations we defined, what the most realistic theory for the movement of cricoarytenoid joint is. The clinical aspects of this study are detailed in the following part of the thesis.

Clinical part

"Early" vocal cord laterofixation for the treatment of bilateral vocal cord immobility

The vocal cord immobility (VCI) often reversible in the first year, thus complete functional recovery can be expected later. In case of bilateral development of this problem, the usually severe suffocation necessitates for urgent intervention. *It must provide immediate adequate airway at least up to the first year and it must be reversible from the view of laryngeal functions.* In the routine clinical practice only the tracheotomy was suitable for this requirements until the end of the last century. Since 1995, we have introduced routinely first a new, clinically really applicable treatment concept for the acute, minimally invasive solution of the dyspnea *without tracheotomy* adapting a modified *Lichtenberger's endo-extralaryngeal* suture vocal cord lateralization technique (1982) for the idea of *Ejnell's and Tissel's* "reversible vocal cord laterofixation" (1993). *The surgical modification mainly turned* *attention to the unit of the cricoarytenoid joint and vocal cord in order to optimize the surgery for the concept of "early" vocal cord laterofixation.* The aim of this study:

- to examine the applicability of the surgical technique (duration, intraoperative and early postoperative complications)
- to evaluate the functional results from the point of view of breathing, aspiration, postoperative complications in the first year (when the paralyses are potentially reversible)
- to justify the reversibility of the procedure, when one or both vocal cord recovered, and the fixing sutures were removed.
- to evaluate the functional results of the procedure after the first postoperative years

Minimally invasive surgery for posterior glottic stenosis

Many different endolaryngeal or usually extralaryngeal procedures have been devised for the scarred vocal cord fixation in the posterior commissure, but even the most successful procedures share is that the temporary tracheostomy might have to be sustained for an extended period of time or the procedure causes drastic irreversible damage in the laryngeal structures in the cases when the intact innervation theoretically provides complete functional solution. Since 1995, we have introduced a new treatment modality, which has given good functional results and spares patients from tracheostomy. The surgical procedure consists of *the endoscopic CO_2 vaporization of the scar combined with our modified (temporary) endo-extralaryngeal vocal cord laterofixation.* The aim of the study:

- to examine the applicability of the surgical technique in different degree of stenosis (duration of surgery, intraoperative and early complications)
- to evaluate the functional results depending from the degree of stenosis: breathing function immediately after the procedure and after the releasing of the vocal cords, the reversibility of the procedure from the point of view of vocal cord function
- the evaluation of the long term results in serious stenoses, in which the vocal cord recovery is not expectable

Vocal cord lipo-augmentation for the phonosurgery of unilateral vocal cord paralysis

The vocal cord augmentation is one of the most popular phonosurgical procedures for treatment of the unilateral vocal cord paralysis. In our Clinic, first in Hungary, we introduced the vocal cord augmenation by autologous fat in 1996. We modified the original vocal cord augmentation method in some aspects, which make possible the more physiological medialization take the unit of the cricoarytenoid joint and vocal cord in consideration. In order to achieve more appropriate intraoperative closure control of the vocal cords in spite of the general anesthesia, we have introduced the *myorelaxation controlled narcosis in total intravenous narcosis with combined JET- and intubated ventilation.* The aim of the study :

- evaluation of the clinical applicability of our modified surgical technique
- evaluation of the functional results, by video-laryngostroboscopy and objective and subjective voice analysis
- to examine the survival of the implanted fat tissue in the vocal cords, by MRI and histological methods.

I. CHAPTER–EXPERIMENTAL PART

I. 1. Surgical-anatomical and neuromyographical study of Galen's anastomosis

I. 1.1. *Historical background*

Throughout the history of laryngology, investigations have studied and compiled theories about the vocal cord in cases of paralysis, the physiologic basis for the fold position and functional deficit, and the prognosis or likelihood of recovery. According to *Semon* (1) (1881) (Semon-Rosenbach law) the only adductor centers have mutual cooperation and anatomical connections effectively protect the adductor muscles against disease producing influences. He felt that the abductors are more "automatic" and therefore they have less resistance against disease-producing causes. *Jackson and Jackson* (2) (1937) agreed with the above opinion, and stated that with any lesion of the recurrent laryngeal nerve (RLN) the abductor muscles 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: 3) 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* (4), in 1957, on the normal electrophysiology of the larynx, many laryngologists have concentrated on diagnosing by laryngomyography (LMG). *Dedo* (3) reconfirmed the *Wagner-Grossman* hypothesis in 1970 on 52 patients by electromyography. Conversely, many other authors debated this theory. *Hirano at al* (5), 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* (6) 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* (7) 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. (8) 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* (9) 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.* (5) 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 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.

Benninger et al (10), 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* (11) animal studies also demonstrated that *variability in the vocal fold position was due to random reinnervation.*

Crumley and McCabe (12), 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. (13), 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* (14), 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.: 15). 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.

Ónodi, in 1902, provided a detailed discussion of this question in his academic publication entitled " A gége anatómiája és fiziológiája (The anatomy and physiology of the larynx)". According to his examinations- macroscopic dissection-performed mostly on dogs, he found that one part of the fibers of AG gets into the path of the RLN and partly ascends and innervates the subglottic area (15). The other part descends and forms tracheal branches that innervate the trachea as deep as the upper four tracheal cartilages. He supported the existence of this connection by many contemporary literary data (15). *Réthi* found fibers in the AG running directly to the internal muscles on dog and human anatomical specimens (14). In spite of this, the AG is mentioned in the latter publications that deal with the nervous system of the larynx only superficially or not at all (16,17,18). One possible reason for this is perhaps that in the classic anatomical books the AG is considered to be only an anatomical variant, which can be found only 30-60% in humans (19).

Development of the examination methods has turned the attention to this question again, from the late eighties. During the dissections of 47 cadaver larynges *Migueis at al.* (19) could find the AG- as a branch or more frequently as a plexus- in every case. Sensory fibers that originate in the subglottic area and run trough the AG were detected by the examinations of neurodegenerative and axonal transport mechanism in animal experiments (20, 21) that were carried about by a work team of the University of Bordeaux.

In our study, in 1992 (I, II, XIV) made on dog larynx and human intraopertative anatomical investigations we tried to confirm *Réthi's* theory on an experimental basis. Our primary goal was to justify the presence of the anastomosis and to clarify the surgical-anatomical details of AG that has been left out of consideration so far. The other aim was to study the physiological role of the anastomosis in the laryngeal innervation: to examine the supposed motoric activity in the anastomosis; to provide details about the participation of the SLN via AG in the sensorial innervation.

I. 1.2. *Subject, method*

The animal examinations were performed on canine larynx (Fig. 1 a), which is a frequently used model in literature (hybrid dogs, n=5, average weight: 24.7 kg), under intravenous anesthesia (sodium pentobarbital 30 mg/kg) without the use of any myorelaxant with spontaneous breathing. An arciform neck incision was made at the level of the cricoid cartilage to expose the larynx and trachea then tracheostomy was performed, and the thyroid ala was partially removed on the both side. Both SLN were approached separately. First we examined the running of the external and internal branches of the nerve, than followed the inner one in the larynx. We searched for the connection between the lower and the upper laryngeal nerve during the dissection of the internal branch of the SLN. For the examination of AG activity we used our modification of a neuromyographic method suggested by *Sasaki and Suzuki* (23) (Fig. 3 a). The stimulating bipolar electrode was fitted to the branch that was running down (this corresponds to the upper part of AG) about 1-1.5 cm far from the division of the internal branch. The conducting bipolar needle-electrodes were inserted into the ipsilateral TAM as one of the adductor muscles of the larynx and into the abductor PCAM. The examined nerve was stimulated by a single, rectangular stimulus with 1 V voltage, and 200 msec. stimulating range. *Medicor ST3* neurostimulator and *Medicor TR4653* oscilloscope

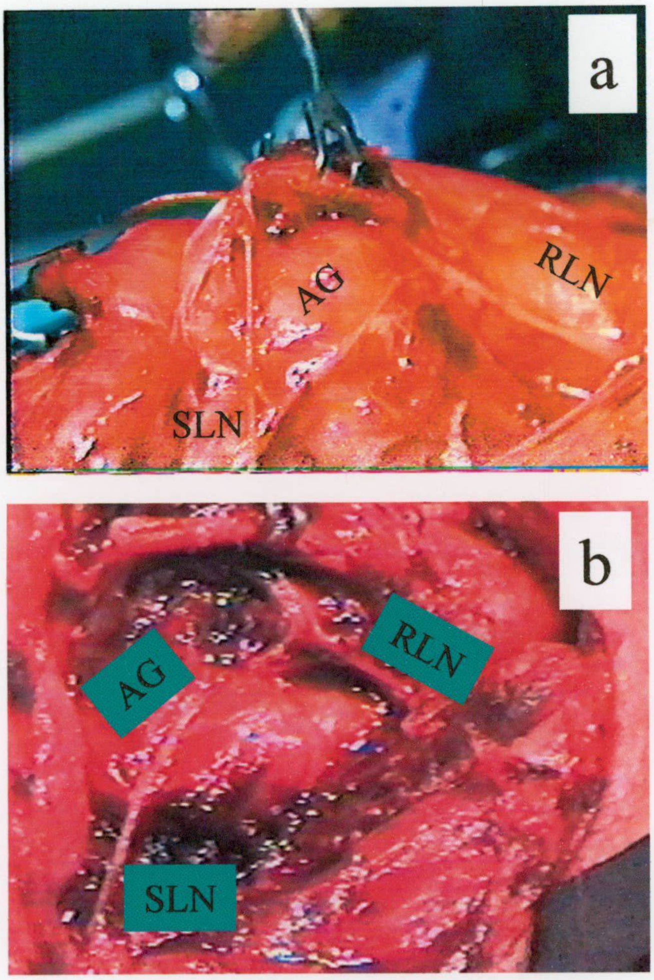

Fig. 1: The Galen's anastomosis (*AG*) in dog (a) and in human (b). There is no fundamental difference in the anatomy.

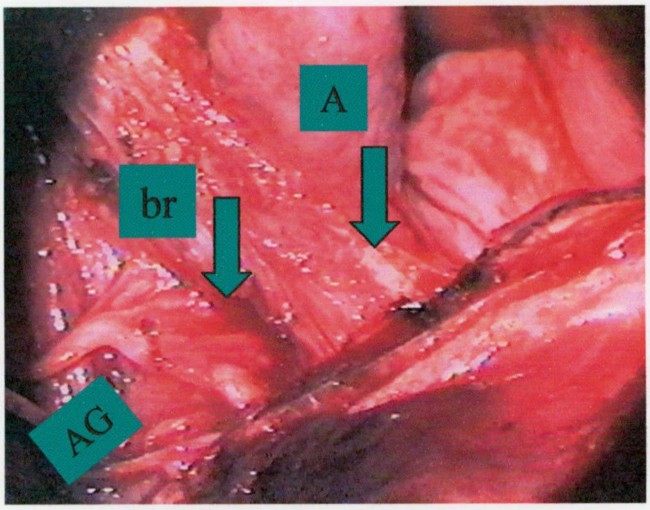

Fig. 2: Branches (*br*) run from the AG into the interary muscles. *A*: tip of the arytenoid cartilage. The picture is made with operation microscope during human supraglottic laryngectomy.

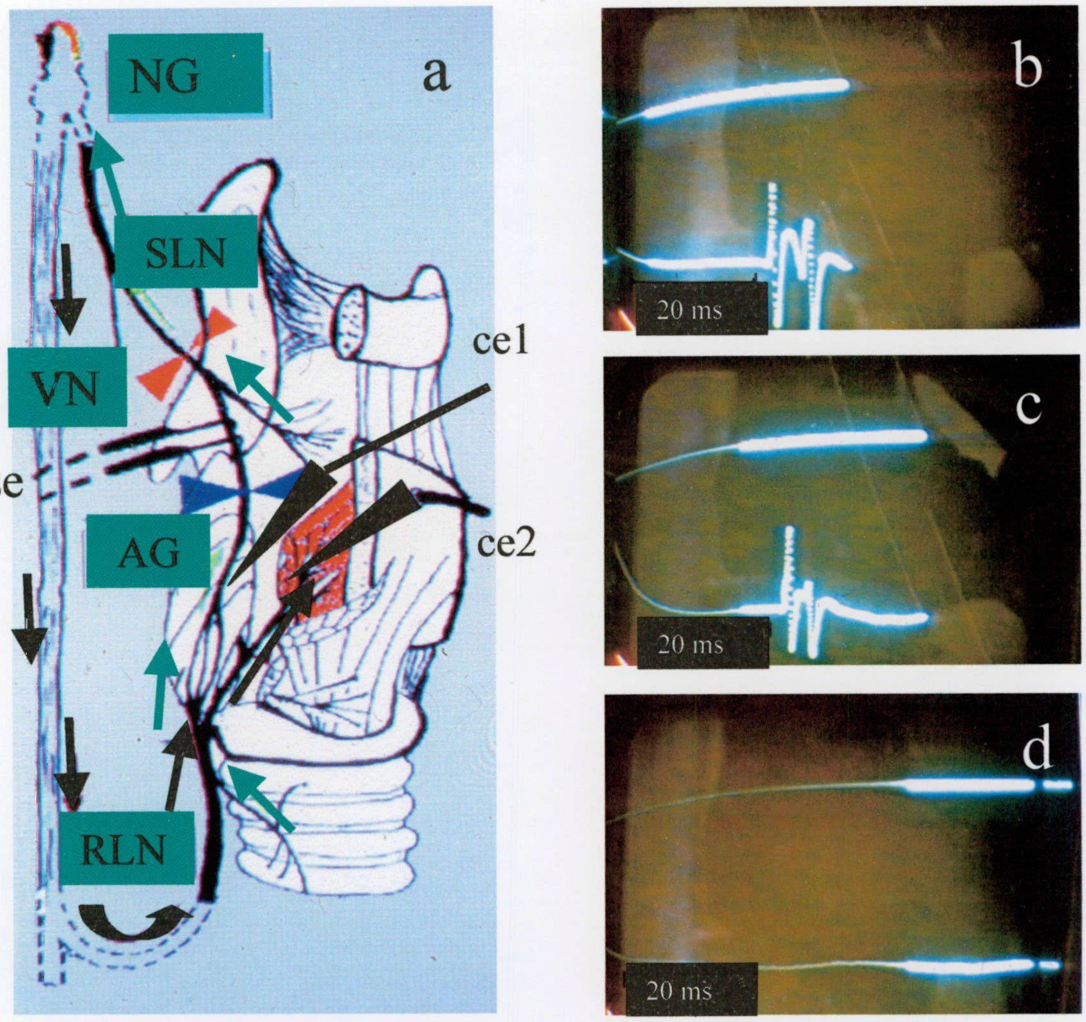

Fig. 3: Neuromyographical study of AG.: **a**: Sketch of the study. *VN*: vagal nerve; *se*: stimulating bipolar electrode on the upper part of AG; *ce1*: conducting bipolar electrode in the PCAM; *ce2*: conducting bipolar electrode in the TAM; *red arrows*: cutting of the SLN above the stimulation; *blue arrows*: cutting of the AG under the stimulation; green arrows: afferent sensorial stimuli running up to the SLN and the NG through the AG from the subglottic area; *black arrows*: efferent stimuli running to the adductors through the VN and RLN. **b**: Registered responses during the measurements and after cutting the AG under **(c)** and above **(d)** the stimulation. (The upper curves are gained from the PCAM, the lower curves are gained from the TAM). See further details in the text.

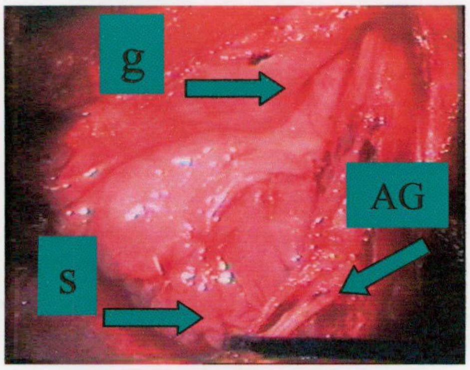

Fig. 4: Glottis closures after stimulation by the electric field of a bipolar cauter during supraglottic laryngectomy. AG: Ansa Galeni**;** *g*: glottis; *s*: stimulation

were used for the examination. The evoked potentials were recorded from the monitor of the oscilloscope by a *Panasonic MS 1* video camera.

First we registered the place of origin and latency of the evoked potentials. In order to survey the direction of the stimulus we cut through the AG first distally then proximally from the stimulating electrode, then we analyzed the changes of the former dates.

In order to control the anatomical details in human, five patients' larynx was studied during laryngectomy (Fig. 1. b). All were men, and their ages ranged from 52 to 67 years. The internal branch of SLN and the RLN were exposed in case of total laryngectomy, then operating microscope and microinstruments were used to identify the connections between the two nerves on the contralateral side of the tumor

I. 1.3. *Results*

Anatomy (Fig. 1. a, b) : The SLN divides into an outer and an inner branch above the level of the hyoid bone. In dogs the external branch - that as we know is the motor nerve of the CTM is considerably thicker than in humans, it is about the twice- triple of it. The same dimensions refer to the innervated muscle, too. We could find the *median laryngeal nerve* in two dogs. This nerve, as *Ónodi* has already been detailed (15), directly comes from the vagal nerve to strengthen the external branch of SLN.

The inner branch of the SLN runs toward the upper corn of the thyroid cartilage, and when it gets there, it divides into an upper and a lower branch. The upper branch innervates the mucous membrane of the laryngeal vestibule and the epiglottis when it crosses the thyroid membrane. The lower branch turns down right beside the upper corn of the thyroid cartilage. Then as it is getting back and down beside the inner side of the plate of thyroid cartilage it gives distinctly visible branches to the cricoarytenoid area (Fig. 2.). These branches were significantly stronger in human. Finally at the level of the lower margin of thyroid cartilage it gives a connection to the pathway of the recurrent nerve. This connection was found in both sides of the larynges in every dog and generally as a plexus in human.

Neuromyography (Fig. 3. b,c,d): Two examined nerves were injured during the dissections, so we could complete 8 neuromyographic examinations on the 5 dogs.

In every measurable case, we could always detect an evoked potential emerging with a definite muscle contraction from the adductor muscle of the larynx (TAM) by the stimulation of the upper part of AG. The latency was always between 20-25 msec. When we cut through the AG under the stimulating electrode, then we could detect a response from the TAM with the same amplitude and latency as the former had. When the SLN was cut through above the level of stimulating electrode, we could not detect any evoked potentials even from the TAM.

Responses could not be registered from the PCAM during the measurements.

I. 1.4. *Discussion*

During our anatomical examinations we could not find any fundamental difference between the laryngeal nerve of humans and dogs. Only minor, mainly dimensional differences are the characteristics of the outer branches. The medial laryngeal nerve, that exists in dogs and strengthens the motor branch of the superior laryngeal nerve, has already been described in the "Anatomia des Hundes" in 1891 (cit.15) can never be found in humans (15). Based on our study, we substantially agree with the descriptions of AG that have been published until now, but we would like to draw attention to some differences. The AG originates from the inner branch of the SLN, but the exact place of the branching off has not been discussed in literature (15, 21). As far as we know the AG is always formed from the first descending branch of the division of the inner branch of the SLN in front of the hyothyroid membrane. According to *Migueis et al.* (19) the AG can usually be found as a plexus, but based on our findings its upper part is always formed of the above mentioned, definite, descending nerve branch. This branch divides into further little braches that can easily be identified by operating microscope, and innervates the ipsilateral cricoarytenoid area, later it forms an acute-angled connection with the RLN at the lower edge of thyroid cartilage (I, II). This connection is represented at the level of the second tracheal cartilage by *Tucker* (18) but the results of *Sander et al.* (23) based on human anatomical study of the laryngeal nerves confirmed our findings (I, II). We found the posterior branch of AG providing fibers to the pharyngeal constrictor muscle in three dogs.

Stimulation of the upper part of AG evokes contraction only in the adductors of the larynx (TAM), but it does not in the abductors (PCM). The evoked potential will remain the same if the AG is cut through under the exciting electrode. This can exclude the direct excitation of the laryngeal muscles and so the existence of the motor axons that run down, through the AG directly to the muscles through in dogs. However, when the AG is cut through above the exciting electrode, these evoked potentials will disappear showing the afferent spreading of the stimuli! The delayed, 20-25 msec latency of the evoked potentials suggests a polysynaptic pathway (I, II) and shows a good correspondence to the latency of the protective laryngeal reflex (24) and in magnitude with other reflexes that have been described in the literature (25). The fibers that run to the muscles are probably sensorial or the afferent axons of the proprioceptive reflexes (I, II). Motor fibers might run only to the muscle of the "Killian ostium" through the posterior branch of AG connecting to the SLN (24).

In spite of this, the second source of motor innervation of intrinsic laryngeal muscles cannot be rejected unambiguously. The results of animal experiences cannot be applied directly to humans. According to our clinical observations, in accordance with others (14, 21) in some cases we found excellent false vocal cord phonation associated with complete bilateral vocal cord paralysis. The intentional good true vocal cord phonation is also difficult to explain only by the effect of *Bernoulli's* law in the majority of cases at the later phase of bilateral recurrent nerve injury. In the prenatal development all branchial arches have their own motor and sensorial nerve, thus the different origins of the human supraglottic and subglottic parts of the larynx (18) also suggest additive motor fibers for the small supraglottic muscles, such as the aryepiglottic muscles or for some part of the interarytenoid muscles (IAM). *Sanders et al* (24) investigated the gross nerve anatomy of the laryngeal nerves by Sihler's stain and found that in all larynxes the RLN and SLN are connected by nerve branches other than GA. The most consistent connection is in the region of interarytenoidal muscles, where RLN and the internal branch of SLN combine a neural plexus (24). Another connecting area is the communicating nerve (CN) in 44 % of human larynxes (27). This connection occurs in the piriform fossa, where continuation of the external SLN passes from the CTM to TAM and terminated in the subglottic mucosa and around the cricoarytenoid joint. Approximately 30% of the axons tested turned out to be motor fibers by positive acetylcholinesterase staining in the CN-s. Probably these neural connections might play role in the residual movement of the paralyzed larynx, but further studies must be performed to confirm this.

Finally we must not forget that the larynx is connected to the complex pharyngeal and upper esophageal muscular system. This muscles activity can cause passive movement in the paralyzed larynx. According to *Réthi* (27), the stylo-pharyngeal muscle might be responsible for the development of the ventricular fold phonation in these cases. The laryngeal part of this muscle is attached to the arytenoid cartilage and so it can pull it toward the midline.

Summarizing the results of our study we can conclude that the stimulations exciting the sensory nerves that start from the sensorial receptors of the subglottic area and travel in AG. These fibers join the other sensory nerves of SLN and get through the nodal ganglion (NG). Then they synapse with the motoneurons of the dorsal nucleus of the vagal nerve (29), which is responsible for the *closure* of the larynx. Thus, the stimulation of the sensorial receptors (mechanical, chemical etc.) of this reflex arc in the subglottic, and upper tracheal mucosa lead to reflectory closure of the larynx. This probably corresponds to the *protective laryngeal reflex originating from these regions,* which prevents the lower airways from aspiration. Though, the role of SLN was well known in the protective laryngeal reflex according to the accepted confines of its innervation territory has been limited to the supraglottic area. Our experience by the electric stimulation of the upper part of the AG during supraglottic laryngectomy (XIV) suggests a similar mechanism in the neural network of the human larynx (Fig. 4.).

I. 2. Analyzing of cricoarytenoid joint movement by picture digitalization technique

I. 2.1. *Introduction and historical background*

The exact anatomy and working of cricoarytenoid joint (CAJ) is still a matter of debate today (29,30,31,32). *Galenus* (i.e.201-130) explained the closing and opening of the larynx by medial and lateral gliding of the arytenoid cartilages on the joint part of the cricoid cartilage (33). *Willis,* in 1829, described the motion of the joint as a forward and backward rocking of the CAJ (34). *Morris and Mcmurrich* (35) and independently from them *Piersol* (36) described it as the combination of three separate movements, forward- backward, outward and inward gliding and rotating and twisting around a vertical axis in 1907. The well-known theory that explained the motion of the joint as a turning around a simple vertical axis comes from *Negus* (1929) according to the international literature (37), although *Navratil* already accepted this theory in his book published in 1887 entitled " The History of the Diseases of the Larynx" (38). After that until nowadays (39) this assumed movement theory can be found in most of the international and Hungarian anatomy books (17,40) and ear-nose-throat text-books (18). In 1969, *Sonneson* returned to *Willis`s* theory, and described CAJ as a cylinder joint with one axis oblique to the medial sagital axis of the cricoid cartilage (41). *Von Leden and Moore* (28), in 1961, described it as a shallow ball and socket joint in which an inward and outward rocking, a lateral and medial gliding, and a limited pivoting occurs. In 1966 *Ardran and Kemp* (42), who studied the larynx radiographically "in vivo", concluded that during abduction the arytenoid cartilage slides backward by approximately 30-40 degrees compared to the position of adduction. In 1975 *Fink* (43) practically returned to *Galenus`* theory, completing it with the possibility of rotation.

These - more or less contradictory - theories are generally based on the top-view picture of the larynx during motion, on the examination of only a few anatomical preparations, on passive movement of the joint or electric stimulation of isolated intrinsic muscles of the larynx. The hidden position and the soft tissues covering the joint do not allow direct examination. The small number of study cases, the anatomical and structural differences between cricoarytenoid joints even in case of a single larynx (23) make the detection of the dominant type of motion difficult. This can also explain why such basic questions like the relation of joint surfaces in different phases of movement have not been clarified (32, 43, 44, 45).

Modern laryngeal surgery, the application of different techniques of medialization or lateralization of vocal chords in uni- or bilatelar vocal cord paralysis, gives this issue a well-defined importance. Digitally processing the shots made by endoscopes, analyzing and averaging the images, we can count the changing positions of the arytenoid cartilage during ab- and adduction. Adding the results to the findings of modern anatomical examinations we can definite what the most realistic movement of CAJ is.

I. 2. 2. Method (XIII)

During the examination we analyzed the movement of the larynx of 50 voluntary men and 50 women (between 17 and 67 years), all with a healthy larynx. The average age was 45 years and previously they did not have a larynx operation or any diseases interfering with the integrity of their larynx. Another 13 persons were excluded due to the lack of cooperation or their anatomical structures (omega-like epiglottis) or because the examined anatomical structures were not recognizable unambiguously.

After applying local anesthetics to the larynx with 10% Lidocain, we introduced the 70° Storz rigid endoscope and recorded the picture of the larynx on SVHS video cassette, in the changing phases of minimum 3 low pitch sounds "i" (adduction) and deep breathing (abduction). During recording we made sure not to change the position of larynx and the optic. The pictures were digitalized by IBM Pentium III computer with a Miro video DC-30 videocard. We saved one picture of the adduction and the best picture of abduction of each larynx. The saved pictures were later analyzed with the help of Microsoft Adobe Premier 5.1c and Microsoft Power Point analyzing programs and the dates were evaluated by Microsoft Excel.

In all the cases we examined the movement of the right side of the larynx. Four points were marked on the pictures of adduction (Fig. 5. a) and abduction (Fig. 5. b): anterior commisure (A); the posterior edge of cricoid cartilage (B), corniculate cartilage representing the apex of the arythenoid cartilage (C1, C2); vocal process (D1, D2). These points could be identified in each examination precisely although sometimes in slow-motion. During recording it was obvious that the position of A and B points did not change and both points could be used as reference points in different phases of movements. By using them the images of adduction and abduction were projected on each other and then the basic pictures were removed (Fig 5. c). The endoscopic techniques can show the top view projection change in the proportion and direction compared to the AB section considered permanent. Because of

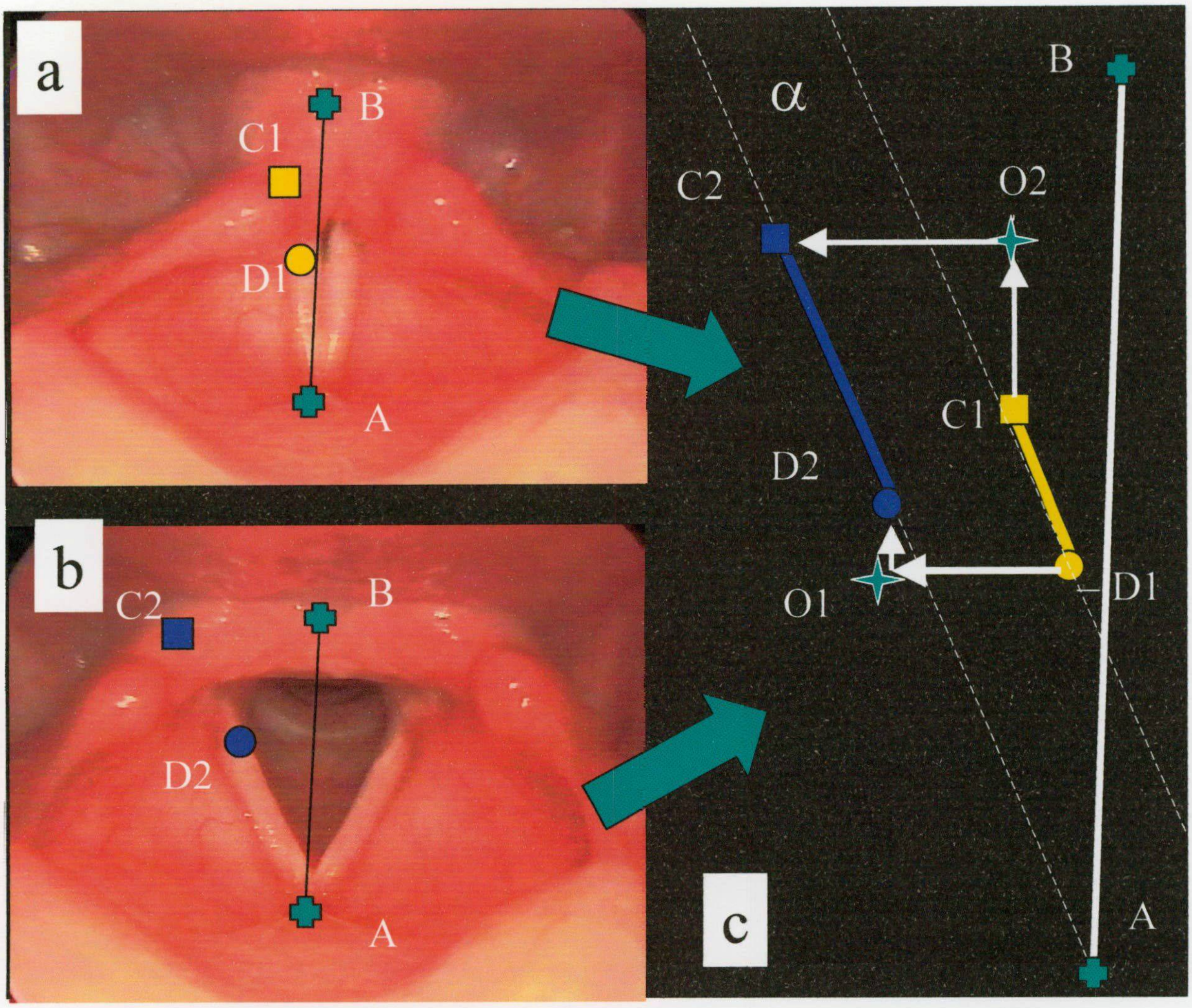

Fig. 5: larynx of a 29-year-old woman, which represents the most common types of movement well. Projection changes of the right arytenoid cartilage on the top-view plane in case of closed (**a**) and opened (**b**) glottis; **c**: Enlarged geometric figure gained by superponation of the two positions; *A* : anterior commissure; *B* : the posterior edge of the middle part of the posterior commissure; *C1,C2* : the corniculate cartilage in case of closed and opened glottis; *D1,D2*: the vocal process in case of closed and opened glottis; α: the angle of C1D1,C2D2 line.

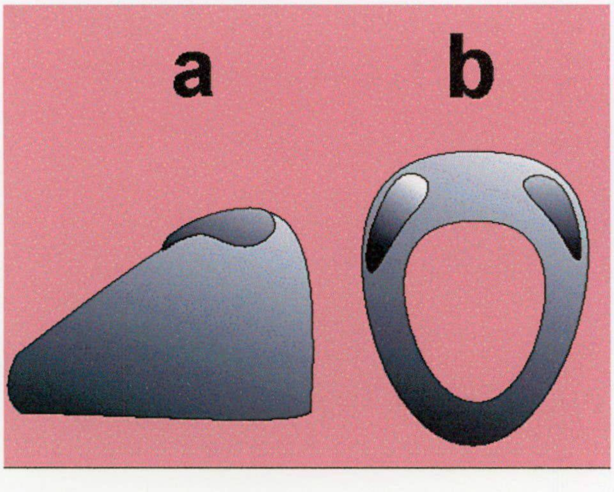

Fig. 6: The simplified sketch of the cricoidal surface of cricoarytenoid joint according to *Wang (32) and Sellars and Keen (47).* a: lateral-view plane; **b:** top-view plane

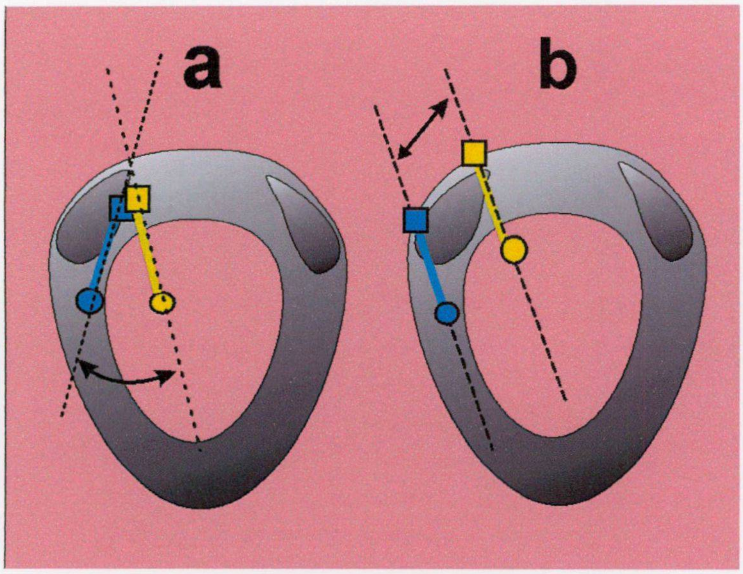

Fig. 7: Position of the right vocal process (ring) and the corniculate cartilage (square) in the top-view plane in case of closed and opened glottis. a: in case of the supposed rotation; **b**: in case of the supposed medio-lateral gliding. Adduction is signed by yellow, abduction is blue.

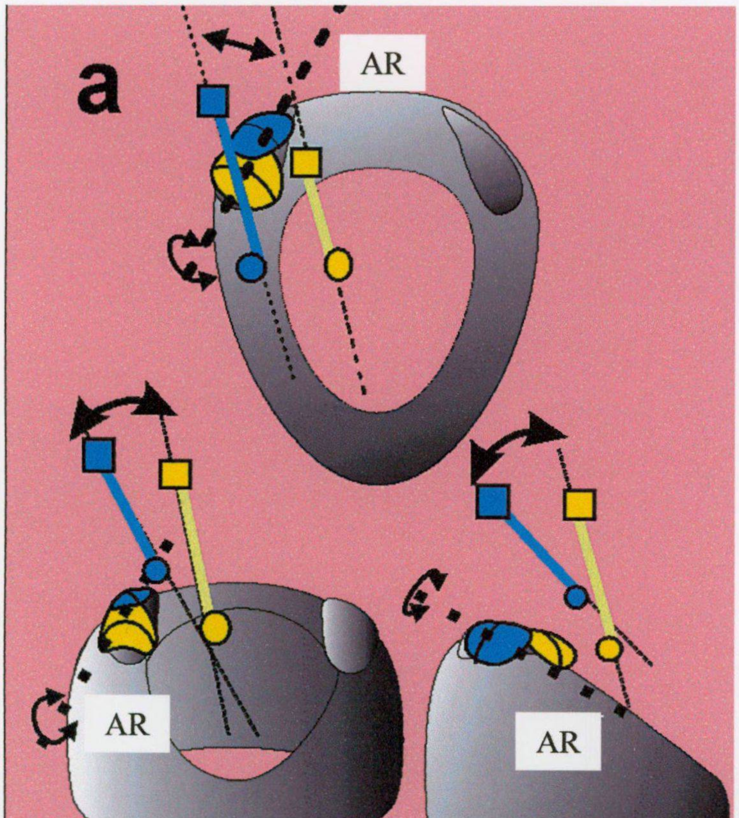

Fig. 8: Position of the right arytenoid cartilage and the relation of the facets in abduction (blue) and in adduction (yellow) according to *Wang (32)*. The vocal process is represented by a ring and the corniculate cartilage by a square. *AR*: axis of rotation

the different anatomical measurements in different larynxes, the movement of the arytenoid cartilages couldn't be compared directly. For the sake of averaging, we applied a normalisation technique used in the vectorial algebra (46). Relative values for movement measured in the above mentioned way were magnified to make all AB sections 10 cm (for better visual understanding), by this way the proportional movement of arytenoid cartilages became comparable and statistically processed.

This way (1.c table) the change in projection from the top view (C1D1 and C2D2 sections) of the arytenoid cartilage getting from adduction to abduction could be examined easily. The angle determined by these sections is (α): the rotation around the vertical axis (α positive: if during abduction the projection of arytenoid cartilage turns outward). The movement vectors of the vocal process and arytenoid apex can be obtained by adding the vector parallel to the medial sagittal axis of the larynx (AB section) (01D2, C102 positive if it points backward, to B) and the vector perpendicular to it (D1O1, C2O2 positive: if the direction points laterally). The changes in projection of arytenoid cartilage was examined by a unpaired t-test, and the difference between sexes by a paired t-test

I. 2.3. *Results* (Table.I)

Table I.: The change in projection from the top view of the arytenoid cartilage getting from adduction to abduction

	C1D1	C2D2	C1O2	O2C2	D1O1	O1D2	CD-C1D1	α (°)
women's avg.	3.32	4.05	1.66	2.07	2.04	0.96	0.73	- 2.47
women's SD	0.86	0.98	0.99	1.01	0.71	0.58	0.76	13.81
men's avg.	3.12	3.98	1.64	2.42	2.18	0.95	0.86	2.78
men's SD	0.75	0.96	1.28	1.22	0.74	1.14	0.93	17.87
average of all	**3.22**	**4.02**	**1.62**	**2.26**	**2.12**	**0.93**	**0.80**	**- 0.12**
SD of all	**0.83**	**0.98**	**1.13**	**1.12**	**0.70**	**0.90**	**0.85**	**15.95**

Avg: average; *SD*: standard deviation; all values are proportionally magnified as AB sections would be 10 cm (for better visual understanding)

The projection of arytenoid cartilage during abduction is significantly ($P=1.32 \times 10^{-15}$) bigger than during adduction (C2D2-C1D1>0), which proves the leaning back of arytenoid cartilage. The two projections determine two separate lines. The angle of the two lines (the rotation angle projected on the top view plane) is 2.78° with men and –2.47° with women, the average is –0.12°, so the two lines are practically *parallel*! The vocal process moves significantly laterally and at the same time a bit backward. The apex of the arytenoid cartilage moves backwards to a greater extent and laterally approximately to the same extent as the vocal process. Therefore, during abduction the projection of the arytenoid cartilage is longer, more backward and more lateral, almost parallel to the projection of adduction. We did not find any significant difference in sex in the angles and motional vectors. The dispersion of values of the examined factors was high.

I. 2.4. *Discussion*

In their classical anatomical studies *Sellars and Keen* (47) explained the structures of cricoarytenoid joints in details on 45 cadaver larynxes. *Neuman et al.* (29) studied 8 cadaver larynxes using CT scan, and *Wang* (32) studied 7 larynxes of cadavers with the help of 3 directional x-ray and they analyzed the prepared video film, and tried to explain the 3 dimensional movement of the joint. *Selbie et al.* (31) analyzed the joint surfaces of two men`s larynx by digitalization of MRI images.

The CAJ is between the arytenoid cartilage and cricoid cartilage. The longer axis of the lower joint surface is 5.4-9 mm and the average is 7.4mm (Fig. 6). It gives a backward pointing angle of 30-60° (32,48) with the median-sagittal axis, but sometimes this angle can be parallel (44). The anterior part of the facet is mainly on the upper surface of the cricoid, but backward it turns to the lateral surface (32). From the side view it is similar to a teardrop with its wider part looking backward and forward from the top view. The facet of the joint is larger in the posterior lateral side and flatter, than the upper anterior side (44). The diameter of facet is convex all through the surface, the largest width is 3- 5.7 mm, the average is 4.2 mm. Significant asymmetry was detected between the joint facets and even in the cricoid cartilage in several cases (44). The arytenoidal facet is concave in its longer diameter and is found at the inferior part of the arytenoid cartilage. It covers the vocal process partially as well. The surface corresponding to the shorter diameter is relatively flat (48) and parallel (47) to the longer diameter of the surface of the cricoid joint. It lies on the shorter, convex axis of the cricoid facet with its longer, concave diameter. Thus, the vocal process is situated medially to the center of the surface of cricoid cartilage and it makes an acute angle facing backward with the longitudinal axis of the joint. Due to this the vocal process has a more or less sagittal position.

The lax joint capsule is attached to the rim of the articular facet (17, 27, 32, 47). The capsule is tightened by a thick, external ligament, the cricoarytenoid ligament, which originates medially from the rim of the cricoid cartilage, and which is attached to the arytenoid cartilage to the mid height posterior-inferior, anterior-inferior, fan-shaped, sometimes divided into two. *Wang* (32) described another two small ligaments, which may strengthen the joint capsule. The posterior one is situated a little bit laterally 'from the cricoarytenoid ligament, and the anterior one originates from the most posterior fibers of the conus elasticus, it is attached to the most anterior- inferior fibers of the cricoarytenoid ligament, to the arytenoid cartilage.

The arytenoid cartilage moves in three dimensions. During our examination we only examined the value of the two top view dimensions, thus the exact movement analysis with figures is impossible. However, if we compare the values of the measured projection with the anatomical configuration of the joint, the main tendencies of the movement of the joint can be cleared. Present theories suppose the separate or combined presence of three main forms of movement: rotation around the axis which goes through the joint and is more or less perpendicular to the top view plane (17, 18, 37, 40) (Fig. 7 a); the medio-lateral gliding on the surface of the joint (34, 43) (Fig. 7 b); additionally a rotation around the axis in the plane of the joint surface, thus rocking forward or backward (31, 41, 45) (Fig. 8.).

The fact that the projections of movement are parallel exclude rotation definitely, since it assumes an angle of minimum 30 degrees (17, 18, 37). *Selbie's* kinetical model also approves this, because this would probably lead to luxation during rotation (31). Medio-lateral gliding during abduction could only be possible, if the arytenoid cartilage moved forward from the back on the long axis of the joint of cricoid cartilage. According to our measurements the projection of arytenoid cartilage moves sidewise, but backward, moreover, the abduction projection is significantly longer, contrary to the approximately same length that we might expect on the basis of mathematical theories. Because of the anatomical structure of the arytenoid cartilage, the anterior surface of the joint is lower than the posterior one, because of the larger distance from lens of the endoscope the projection of the abducted arytenoid should also be smaller. Another important argument against this theory is that the differences between the surface of the joints and ligaments would make only small, approximately 2 mm movements possible (31,48,). The axe of rocking is almost the same as the longitudinal axis of the joint according to *Sonneson* (41). The arytenoids would slide seemingly laterally, but the vocal process gets into a more lateral position and a little bit backwards. *This pattern is the closest one to our results* (XIII). According to *Wang* (32), during adduction the arytenoid cartilage stands on the lower, most superficial and most lateral surface of the cricoid. During abduction it gets upward, medially on the most posterior surface, which turns a little bit outward. This modifies *Sonneson*'s theory in a way that the axis of rotation continuously changes in direction and position during the movement. The kinetic model of movement also supports this (31). The movement of the surface of the joints on each other can be explained partly by the small gliding, partly by the small rolling between the lower hilling and the upper flatter surface of the joint (48). Thus, the joint is most probably a modification of the one axis synovial joint (gynglimus, i.e. mid-pharyngeal joints), in which the lower joint facet is fix (apex of the joint), and it is a little bit turned, rotated to the direction of the axis of rotation (XIII). This movement is also beneficial from the physiological point of view, because the whole arytenoid cartilage together with the vocal process moves outward during inspiration, making the lumen of the cricoid cartilage totally open (fig. 8.c).

During the opening, the vocal process is continuously in sagittal position, and moves a little backward, which gives the illusion of a lateral gliding or rotation. During abduction it moves upward (fig.8.b), so it rises with the vocal cord toward the Morgagni`s vetricule. If this did not happen, then the TAM muscle attached to the lateral surface of the corpus of the arytenoid cartilage and to the vocal process would be a mechanical obstacle to the abduction (32). Theoretically other compound movements may also result in the picture we described (for example the forward-backward gliding of the joint combined with a large backward bending, etc.) but on the base of the geometry of the surface of the joints these movements would need very complicated muscle interactions, which would be practically impossible.

The dominant mechanism of abduction in the "average" CAJ is rocking sidewise, outward and backward with the vocal process and the posterior insertion of the vocal cord and vice-versa in adduction (XIII). Nevertheless, the disperse in the values of movements points to significant individual differences what could be explained by the anatomical variation in surfaces of the joints even in case of two sides of the larynx (44).

The question arises how the precise, vocal cord adjusting mechanism of the adduction is done in this case. *Sellars and Keen* (47) assumed a separate mechanism, a fine rotation at the end of the abduction. According to *Wang* (32) this mechanism is not necessary, because vocal cords - during their development in abduction -, develop from one development plane (49), by this way precise closing during phonation is given. The symmetry of abduction is not necessary during inspiration. In spite of this a small, individual amount of rotation movement in the joints, cannot be excluded as a part of the complex continuous motion (47, 50).

II CHAPTER - CLINICAL PART

II. 1. "Early" vocal cord laterofixation for the treatment of bilateral vocal cord immobility

II. 1.1 *Introduction and historical background*

II. 1.1.1 Etiology of transient and temporary vocal cord immobility.

Vocal fold paralysis is a relatively common diagnosis in laryngology. However, considering the fact that beside the most common neurological disorders many other factor can cause vocal fold fixation it would be better to term this entity as vocal cord immobility (VCI). If an immobile vocal cord regains function, it usually does so within 9 to 12 months after injury. The immobility is defined *transient* if it lasts 4 weeks or less. Only rarely will VCI resolve after 12 months, therefore VCI after 12 months is termed *permanent* immobility. The range in between represents a *temporary* loss of function (51). Etiologic factors of the *permanent* VCI are the following (52): congenital anomalies; posttraumatic endolaryngeal scarifications; ankylosis of the cricoarytenoid joint; paralysis due to inflammation, compression by neoplasm, traumatic nerve lesion due to strumectomy, blunt trauma etc; tumorous nerve infiltration; chronic inflammation.

Unilateral *transient*, and probably sometimes the *temporary* VCI may be more common than is thought; because the symptoms may resolve before an individual seeks medical attention. Nevertheless, in case of bilateral VCI suffocation generally necessitates urgent diagnosis and treatment. The various examples of these VCI can be divided in to the following categories:

Traumatic causes: In spite of the refinement of surgical technique VCI remains a complication of thyroid surgery (53). More than 50% of the paralyses is transient (53, 54) because intraoperative damage commonly results in reversible neurapraxic injury of the RLN. The resolution of immobility may occur over a period of days up to 9-12 months (55, 56). *Shindo et al* (57), using a canine model have demonstrated nerve regeneration 9 months after excising 2.5 cm of the RLN. Bilateral injury most often results from reoperation or operation of malignant tumors (53, 54, 58).

Postintubation VCI is generally the consequence of scar tissue development in the posterior commissure of the larynx (59). Nevertheless, *Cavo* (60) reviewed 36 cases and described another possible mechanism of RLN injury via cadaver dissections. The anterior branch of the RLN can be compressed between the balloon and the thyroid cartilage causing a compressive neuropathy. The most likely site of injury is 6-10 mm below the vocal cords, where the medial aspect of the nerve is unprotected and can be forced against the unyielding thyroid cartilage laterally. This theory cannot be rejected unambiguously, because cases have been reported (59, 60, 61) showing return of normal vocal cord function after the intubation from 1 week up to 2-4 months. Another way of traumatic injury of the RLN is the direct outer compression of the neck by direct neck trauma or strangulation, which may lead to bilateral VCI by stretching the nerve in one of our patients.

Metabolic or toxic causes: Metabolic disorders resulting in VCI are generally hypocalcemia and hypokalemia. Hypocalcemia causing VCI is well known in infants, but it is not considered in older individuals (62, 63, 64), but in our experience it can occur when the parathyroid glands are removed directly or accidentally during thyroid surgery. Enhanced neural excitability leads to repetitive neural firing (tetany) that is clinically represented as VCI or laryngospasm. This is believed to be more dependent on the rate of decrease than the actual serum concentration of calcium. The prompt correction of this leads to rapid return of normal laryngeal function.

The exact pathophysiology of hypokalemy causing VCI is unknown. Intracellular depletion of potassium affects the resting and action potentials of both muscles and nerves, resulting in weakness. This, too, can be resolved fast with the correction of the hypokalemia. (51).

Transient VCI has been reported and it also could be found in our practice after (65) vincristine and other vinca-alkaloid treatment. They can produce reversible cranial neuropathy by interfering with neural axonal transports producing axonal degeneration. Early suspicion of this by the oncologist can result in prompt diagnosis, and cessation of treatment restores normal function.

Neoplastic causes: Both benign (66, 67) and malignant neoplastic disorders (68) can lead to transient VCI. Nerve function may return after surgery or even after radiotherapy (68). The mechanism responsible for the paralysis in these cases is probably a combination of different factors. The direct compresson of the RLN or its blood supply leading to neuropraxia or reversible ischemia is believed to be most common. Inflammation causing neural edema or vascular thrombosis is felt to also occur in case of Hashimoto's thyreoditis.

The adage that preoperative RLN paralysis is pathognomic for malignancy seems to be false. *McCall et al* (66) reported on 14 patients with VCI, and 7 of these cases were found to be benign lesions of the thyroid gland. *Falk and McCaffrey* (69) report on 29 patients with suspected thyroid carcinoma with VCI. Four cases were found to have a benign disease, and in three of them the vocal cords regained normal function after thyreoidectomy.

Infectious, inflammatory and autoimmune diseases: Most frequently toxoplasmosis, and cryptococcal meningitis are the most common neurologic infections in these patients (70). Cranial neuropathies are seen commonly in HIV infected patients as a consequence of acut or chronic meningeal irritation. Appropriate medical treatment can solve the problem in the first case, but the resolution of this laryngeal deficit cannot be expected in the latter one.

Myasthenia gravis is a disorder in which prompt diagnosis can eliminate VCI and dyspnea (71). Systemic lupus erythematosus (SLE) has been associated with cranial neurophathies, including VCI. An SLE related pulmonary hypertension has been shown in postmortem examination to cause VCI by the compresson of the left RLN against the ligamentum arteriosum by a dilatated pulmonary artery (72). *Teitel et al* (73) reported on cases when unilateral VCI fully recovered after corticosteroid therapy. This implicates a vasculitic or antineuronal antibody mechanism in the background of SLE patients with cranial neuropathy.

The duration and reversibility of VCI mainly depends on the severity of trauma, moreover the possibility of some kind of reinnervation cannot be rejected even in case of heavy injury of the laryngeal nerves (57). The other limitating factor is the atrophy of the intrinsic laryngeal muscles due to inactivity. *Zealer et al* (74) demonstrated the histological changes of the PCA muscle after a chronic denervation on 26 dogs. After the resection of 10 cm of the recurrent nerve they examined the loss of muscle weight and atrophic changes in fiber density and diameter, which reflects the reduction of contraction strength of the muscles. The main change of muscle composition occurred because of the increased susceptibility of fast–twitch (Type 2) () fibers to degeneration. Muscle fiber degeneration was negligible at 3 months, but encompassed one third of the fiber population by 7 months. In view of the irreversible nature of fibrosis they felt that reinnervation must delay not more than 7 months after the nerve injuries. In spite of this clinical observations in accordance with our experience have shown that it is worth waiting 6-12 months for spontaneous recovery of vocal cord function (X).

The above mentioned examples demonstrate the potential reversibility of VCI in many cases in the first year, but the appropriate medical therapy, nevertheless, can promptly resolve dyspnea in bilateral VCI only in a few cases. The magnitude of this depends on the position of the vocal cords and on the cardio-respiratory reserve of patients. Intubation can be an urgent solution of severe cases, but if resolution has not presented within days tracheotomy is indicated generally. The classic, irreversible vocal cord lateralization procedures are suggested after this early, potentially reversible period as the final surgical solution.

II. 1.1.2. *Surgical techniques for the treatment of bilateral vocal cord paralysis*

The solution of the upper airway dyspnea was an open question from antiquity. *Asclepiades* (128 BC) has already described that surgical opening of the trachea can eliminate suffocation and by inserting a metal tube into the trachea he could ensure the long time efficacy of this intervention (cit: 38). During the centuries this tube has developed to the modern airway canula and there was no alternative in the treatment of VCI-caused suffocation to tracheotomy until the beginning of the 20th century. The search for a compromise between socially satisfactory phonation with an airway compatible with active life is the main management problem even nowadays. To find this ideal intervention more than seventy types of published glottis widening surgical methods have been developed so far (52). The most important steps of this effort from the view of this thesis are the following:

II. 1.1.2.1. *Vocal cord lateralization techniques via external approach*

In the second decade of the 20th century many glottis widening procedure trials were reported to save patients from the lifelong canula bearing. One of the first, *Réthi*, in 1921, reported on his surgical method (cit: 76). He achieved good results from the point of view of breathing with his type I technique by the opening of the cricoarytenoid joint and submucosus exstirpation of the contracted adductor muscle through laryngoffissure (14). In 1922, *Jackson* (77) reported on ventriculocordectomy, which resulted in satisfactory airway but permitted only a whispering voice, thus *Hajek* (78), in 1932, offered preferably the use of a valve airway canula in this case.

Citelli published the idea of the simple surgical removal of a vocal cord (cit.: 27). Nevertheless, the result was only temporary, and the secondary fibrous glottic distraction often resulted in dyspnea again. *Réthi* (27) also expressed his opinion about *Weigartner's* and *Hoover's* (79) submucosus cordectomy and *Kofler's* modification by cauterisation. According to him, these interventions are ineffective in the long run for the same reason, and they caused severe permanent loss in voice quality. *Wittmack*, (cit.: 27) in a modification of the Réthi I procedure tried to achieve a vertical gap between the two vocal cords, by the resection of one of the vocal processes and the inferior part of the arytenoid cartilage. *King* (80) introduced an extralaryngeal arytenoidopexy in 1939. The procedure is based on the freeing of the arytenoid cartilage from all its muscular and ligamentar attachements except for the vocal muscle, then it is fixed to the posterior edge of the thyroid ala and to the omohyoid muscle. Two years later, *Kelly* (81) performed *arytenoidectomy* through a window of the thyroid cartilage, which he improved by fixation of the corresponding vocal cord in order to conserve the good glottis opening. Modified arytenoidectomy was described by *Woodman* (82), in 1946, with lateralization of the ipsilateral vocal cord by submucosal suture of the preserved vocal process and fixation to the inferior horn of the thyroid cartilage. *Réthi* proposed a new concept of laryngoplasty in 1955 (76). This consisted of a *posterior laminotomy of the criocoid cartilage* and stenting of the larynx by his combined dilatation airway canula. Later he modified his technique by cartilaginous fragment insertion into the cartilaginous gap. This and various types of modification of the procedure (83) are widely applied procedures even nowadays especially for the treatment of posterior commissure scar fixation, because this concept keeps the integrity of the CAJ and the vocal cords.

In 1968 *Downey and Keenan* (84) performed an arytenoidectomy via laryngofissure, and *Helmus* (85) ameliorated this technique through the use of operative microscope 1972.

Woodman (86), in 1949, *and Schobel* (87), in 1986, modified *King's* technique. Woodman, after the resection of the body of the arytenoid cartilage, sutured only the vocal process to the thyroid cartilage. *Schobel*, after the liberation of the arytenoid cartilage, fixed it to the posterior edge of the thyroid cartilage by two or three sutures furnished by "Schobel knots". This provided some extra rotation for the arytenoid joint. *Pytel* (52), in 1997, published his excellent results with his modification of *King- Schobel* technique. He passed the fixation of the arytenoid cartilage to the omohyoid muscle and used only two rotating sutures after he completed the posterior opening of the joint.

II. 1.1.2.2. *Vocal cord lateralization via endoscopic approach*

All the above mentioned procedures were performed via external route, and generally required laryngofissure, or partial resection of the thyroid ala or a relatively large mobilization of the pre- and perilaryngeal soft tissues. The development of laryngeal endoscopic techniques facilitated the processing of the minimally invasive surgical techniques in this field too. In 1948 *Thornell* (88) published the first micro-instrumental *arytenoidectomy by an endoscopic approach.* Kleinsasser, in 1976, expanded this technique by a partial submucosus cordectomy (89). *Strong, Jako and Vaughn* (90) suggested the use the carbon-dioxid (CO_2) laser in laryngeal surgery and then first mentioned the *use of CO_2 laser for arytenoidectomy* in 1972. *Kirchner* (91) described laser submucosus cordectomy combined with a temporary external lateralization of the spared vocal cord mucosa in 1979. *Eskew et al.* and (92) *Osoff et al.* (93), in 1983, reported on successful decanulations after *laser arytenoidectomy. Posterior cordectomy* by CO_2 laser was performed by *Dennis and Kashima* (94) with satisfactory results as reported by the authors in a series of 6 cases in 1989. *Crumley* (95), in 1993, and *Remacle* (96), in 1996, proposed a partial *arytenoidectomy* with sparing the vocal processes to ensure a relatively good phonation.

In 1982, and 1983, *Lichtenberger* (97, 98, 99) described his initial research experience with his new device that allowed endoscopic placement of *endo-extralaryngeal* sutures. An *endo-extralayngeal needle carrier* (Fig. 10.) was described (99) that allowed placement of sutures endoscopically under direct vision and then are brought to the skin and secured. In his early issues (100, 101) he introduced two types of human application in case of bilateral vocal cord paralysis. In "type A" the paralyzed vocal cord was lateralyzed only by a 2-0 nonabsorbable suture inserted over the posterior part of the vocal cord endoscopically by the instrument. Then the suture was fixed from an external neck incision on a small silicon platelet placed directly to the thyroid ala. In "type B", he combined this technique by an extensive submucosal resection of the TAM in order to diminish the pulling effect of the contracted muscle, and to achieve an extra widening by reducing the volume of glottic tissue. The endo-extralaryngeal suture technique provided a good temporary fixation of the spared medial vocal cord mucosa by a silicon platelet placed over the skin. In contrast he found that the results of "Type A" technique were uncertain in his published two patients. In 1994, he introduced his third technique: the combination of Type B technique with endoscopic laser arytenoidectomy (102). The type B, later "endo-extralaryngeal microsurgical lateralization (EExLL), procedure was indicated in case of a mobile cricoarytenoid joint. The "EExLL with arytenoidectomy" was originally indicated in case of fixed cricoarytenoid joint with or without submucosus resection of the vocal cord (103,104). The advantages of these latter techniques include simplicity in technique, the glottic mucosal preservation, which can prevent postoperative scar formation in the posterior commissure (105). The disadvantages include increased breathiness of the voice, as with most lateralization procedures, and the occasional need to perform a bilateral operation. Summarizing the published results

(103,104,106) we can conclude that these interventions provide one of the best efficacy from the point of view of airway stability in the long run in case of permanent VCI.

II. 1.1.2.3. *Reinnervation procedures*

The simplest procedure in this group is the *liberation of the nonfunctioning nerve* from adhesions and scar tissues. This neurolysis had been carried out to some measure of success by *Miehlke* (107). Surgeons have attempted to perfect *end-to-end anastomosis* of the RLN even in the beginning of the 20th century (cit: 76), but it was only in the last decades that these efforts have been partially successful. The use of operating microscope and microsurgical techniques have permitted the precise approximation of the damaged nerve. In 1969, *Doyle* (108) reported five cases of functional recovery in six patients operated within 5 days after their injuries. The timing of the reconstruction appears to be crucial for the success of neurorraphy. The first two weeks are considered decisive. *Berendes and Mihlke* (109) reported success with an *autogenious transplant of RLN by greater auricular nerve* 10 weeks after the injury. Mihlke (110) also developed a technique for *isolating the RLN bundle in the vagus nerve and "shunting" the liberated segment to the distal nerve stump of the severed nerve* near to the larynx.

Frazier (111), in 1926, attempted to cure the paralysis by *anastomosing it with the descending branch of the hypoglossal nerve*. He reported improvement in six out of ten patients. *Doyle* (108) *and Calcaterra* (cit.:112) have attempted *direct nerve implantations into the posterior cricoarytenoid muscle* using the proximal segment of RLN or the phrenic nerve. More successful has been *the composite nerve-muscle* transplant with the ansa hypoglossal nerve and the adjacent pieces of muscle from the omohyoid muscle described by *Tucker* (18). He reported success in 40 of a series of 45 cases.

In spite of this encouraging pioneer results, these techniques have not been able to get into the practice. Neurolysis has gained some popularity, but it has the risk of leading to more severe nerve damage. These theoretically superior procedures, compared to standard lateralization techniques, must be made in the earliest part of paralysis diminishing the possibility of spontaneous reinnervation. Moreover, perfect end-to-end anastomosis is not possible, because the axons running in one branch to the opposite muscles probably would be misdirected, which may cause synkinetic immobility. For this reason generally only the PCA muscle is attempted to reinnervate. Nevertheless, without the appropriate reinnervation of the adductor muscle the result would not be complete, because the developing synkinesis or fibrosis can diminish the effect of abduction (14,76). The variable communicating anatomic anastomosis revealed in both sides and between the RLN and SLN in the human (23) and especially the canine larynx (20) may have benefit to the results generally detected over six months after surgeries. In spite of these facts, these reinnervation attempts cannot be kept practically useless as *Réthi* (76) declared it in the beginning of the 20th century, but more experimental study is necessary until they can be introduced into the practice of the treatment of bilateral VCI. But in the case of unilateral VCI they can be exciting new ventures in the field of phonosurgery dealing with the restoration or replacement of the injured laryngeal nerve and its potential for voice improvement (112).

II. 1.1.2.4 *Vocal cord lateralization without tracheotomy*

The previous historical enumeration of the development of surgical techniques clearly demonstrates the almost straight development to the minimally invasive endoscopic techniques from the originally applied external interventions. Nevertheless, this development generally includes the variation of some basic elements as: partial or complete, simple, or submucosal resection of one or both TAM with or without arytenoidectomy; the strong and irreversible laterofixation of the vocal cord(s) or the sacrify of the cricoarytenoid joint structure etc, in relation with the practically accessible technical instrument. In the end of the 20th century laser arytenoidectomy with or without cordectomy has become the most fashionable way of treatment (93, 95, 96, 103, 104, 106, 113). These techniques, as it was discussed earlier, are not suggested in the first, potentially reversible 6-12-month period of the paralysis, because they cause more or less drastic, irreversible change of the glottic anatomy, thus in phonation. So the conventional, "golden standard" surgical treatment strategy has not changed in case of severe suffocation (18): ***the first step is tracheotomy to prevent the patient from choking, and minimum six months later a common definitive surgical intervention to open up the paralyzed glottis.***

Disadvantages of this surgical strategy originate from the presence of tracheotomy. Besides the well known loss of the "quality of life" from the point of view of social, somatic and psychical acceptance of this situation, tracheotomy may cause many severe somatic side effects. In one major literature review the overall incidence of tracheotomy complications ranged from 6,7% to 48%, with a mortality of 1,6% (114). The individual incidence of several major tracheotomy complications have been reported: postoperative hemorrhage, 1% to 37%; pneumothorax, 0% to 4 %; tracheoinnominate fistula, 0.4% to 4.5%; tube occlusion, 2.5%;

tube displacement, 0% to 7% and subcutaneous emphysema, 0% to 9%. In addition they report frequent aspiration difficulties and risk of wound infection. Another problem is the increased discharge as a consequence of the mechanical irritation of the tracheal mucosa, and last but not least "hasty" tracheotomy is one of the most common etiological factors of laryngotracheal stenosis (Fig. 9. a, b). Finally, this procedure increases the cost and length of hospital stay and ambulantory care. Hence, it is clear, that when suffocation presents only in exertion, the *watch and wait policy* is preferable to tracheotomy, although this approach may restrict the patient's daily activities.

Until the end of the 20^{th} century tracheotomy formed the basis of the safe lateralization procedures. The postoperative edema caused by the extensive soft tissue irritation of the external approaches, especially the procedures necessitating laryngofissure, the use of an intralaryngeal stent (14, 76, 105) clearly indicates the need of this. *Réthi* (76), in 1955, routinely applied tracheotomy two weeks before the final procedure even in cases, when the patient was free from canula. The external procedures made without laryngofissure, *Schobel* lateralization without tracheotomy in more than 50 % of the their 30 patients (52).

Nevertheless, the real breakthrough in this question can be related to the development and spreading of minimally invasive endoscopic techniques. *Lichtenberger* was among the first to publish about the use of *endoscopic techniques without tracheotomy* (100, 101). In his issue published in 1985, he described two patients, who underwent the lateralization procedure in nasotracheal narcosis to spare them from the unpleasant consequences of tracheotomy. To avoid the technical difficulties of translaryngeal intubation *Incze et al* (115), in 1984, reported on the *Diazepame (Seduxen) and γ-hydroxy-butiric acid combination anaesthesia without intubation for the microsurgery of the larynx.* Nevertheless, this technique could not get wide acceptance because of the risk of possible postoperative suffocation (74). The introduction of *translaryngeal high-frequency JET ventilation* as a part of *Lichtenberger's* surgical technique was the next step in order to improve the results. *Lichtenberger and Toohill* published their series of 54 and 59 consecutive patients who had been operated on with one of the endo-extralaryngeal lateralization techniques in the Szent Rókus Hospital in Budapest, Hungary and the Medical College of Wisconsin Affiliated Hospitals, Milwaukee until 1997 (103) and 1998 (104). Among these patients they could report on 5 and 9 patients successfully treated with submucosus cordectomy and endo-extralaryngeal lateralization (Type B or EExLL) without tracheotomy. *Woodson* (106) also reported the success of this technique on three patients in 1991.

II. 1.2 *"Early" vocal cord laterofixation*

Theoretically, the urgent treatment concept must satisfy two important criteria in case of a bilateral VCI in the critical potentially reversible early period. *It must provide immediate adequate airway at least up to the first year and it must be reversible from the point of view of laryngeal functions.* As the previous cases demonstrated, the traditional vocal cord lateralization procedure can be preformed without tracheotomy, especially by the endoscopic intervention; nevertheless, the damages cause irreversible phonation insufficiency (27,103,104,106). The long-term success of the theoretically superior reinnervation procedure has been about 80%, but reinnervation requires also a delay of 4 to 6 months after surgery before active abduction may begin (18).

To solve this antithesis many authors suggested partial cordectomy (93), or some type of partial arytenoidectomy (95,96) to diminish the surgical injury, but the voice damage remained significant, and the improvement in breathing was more theoretical than practical in the long run (96). The large series of laser cordectomies (116) made for vocal cord cancer also prove the relative fast scar formation in the place of removed tissues.

Another approach of this problem would be, if the prognosis of paralysis could be diagnosed directly after the nerve injury. LMG is actually the only electrophysilogical test that may be able to assess the state of muscle denervation and reinnervation (117). The completely denervated larynx with spontaneous irritable muscles with fibrillation potentials, positive sharp waves, complex repetitive discharges, and/or electrical silence on the LMG would theoretically be candidates for permanent surgical procedures. According to *Woodson* (118), however, fibrillations and polyphasic potentials may be difficult to detect, assessment of voluntary interference requires subjective judgment, and complete denervation with electrical silence is rare. Most patients have varying levels of regenerated or residual muscle activity. In patients with prolonged VCI, the presence of muscular unit potentials on LMG may be the result of misdirection of regenerating nerve fibers. Conversely, LMG may be abnormal in spite of laryngoscopical evidence of normal vocal cord mobility (119). *Thumfart* (120) reported a series of 184 patients with vocal cord paralysis and 1-year follow-up, in which the prognosis of LMG was not consistent with the LMG findings in 25 % of patients. These uncertain conditions may explain that the clinical value of LMG is dependent on the experience of the clinician (118), but LMG is becoming more useful, and it promises to save both time and cost in the future.

Main steps of the solution of this dilemma were the followings:

In 1993, for the first time in literature *Ejnell and Tissel* (58) reported on 4 cases– operated on for advanced thyroid malignancy -, in which an adequate airway was achieved by unilateral simple "acute, reversible" *exo-endolaryngeal* vocal cord lateralization *immediately* after the bilateral recurrent nerve injury. The surgeries were made by an externally inserted non-absorbable suture loop around the posterior part of the vocal cord *without any resection of the laryngeal tissues*. After recovery of the contralateral vocal cord movement the laterofixating threads were removed, and in two cases the previously laterofixated vocal cords regained normal movement. The other important factor was the development of the *endo-extralaryngeal* suture technique by *Lichtenberger* (98, 99)

Adapting our modification of *Lichtenberger's* endoscopic "A" technique to *Ejnell's and Tisell's* original idea, since 1995 we have introduced a new, minimally invasive concept for the management of bilateral VCI. *We extended the indication to all types of bilateral VCI within 6 months from the paralysis versus tracheostomy, and to patients, in whom the suffocation presented only on exertion in order to improve their quality of life*. Thus, we called the procedure an *"early" (and temporary in case of vocal cord recovery) lateralization* of the vocal cord. We first reported on about this concept on the 3rd Congress of the European Federation of Oto-Rhino-Laryngological Societies in 1996 (XVI). Since that, we have further modified the surgical technique on the basis *of the physiological movement of the cricoarytenoid joint* (III, IV, VI, X, XII, XVIII, XX), thus this concept has became the primary treatment concept of the bilateral VCI of our clinic with increasing Hungarian and international acceptance.

II. 1.2.1. ***Patients and methods***

II. 1.2.1.1 *Patients*

Forty-two consecutive patients (33 women and 9 man) were operated within six months from the detection of bilateral VCI (Fig. 13. a) from August 1995 to August 2002. Another four patients visited our clinic for bilateral VCI developed after thyroid surgery diagnosed earlier by an otolaryngologist, but our endoscopic findings revealed the beginning recovery of vocal cords in these cases. Ages of the operated patients ranged from 22 to 81 years, average 49 years. The follow-up period was between 2 weeks to 74 months (mean: 29

months) at the time of this study. In 33 cases the paralysis developed after *thyroid surgeries* and in one case after *a tracheal resection of a postintubation stenosis.* These interventions had been mainly performed previously in the referring general surgery departments of the Medical Faculty of the Szeged University of Sciences. Bilateral VCI presented *after strangulation of the neck* in one case. *Inoperable infiltrating esophageal or thyroid* carcinoma caused the VCI in three cases. There was a known unilateral VCI in the history in two patients, *and the contralateral vocal cord immobility presented after a CO2 laser resection of a marginal laryngeal tumor involving the aryepiglottic fold on the other side* (XI). One other patient was admitted to our clinic with bilateral VCI detected after a viral infection of the upper airways. In another one a viral infection was also the preoperative diagnosis, but intraoperative findings revealed the *ankylotic fixation of both cricoarytenoid joints.* In the remaining two cases *etiology remained unknown* in spite of the correct examinations (CT, MRI etc.). The time between the onset of paralysis and the laterofixation procedure ranged from 1-122 days (mean: 17 days).

In 12 cases, the patients were (re)intubated, and 9 patients were tracheostomized before they were sent to our clinic for the vocal cord lateralization procedure. The other 21 patients experienced moderate to severe stridor at rest and severe stridor on exertion (Fig.: 13 a.). Among the 5 patients who had undergone reoperation of the thyroid gland 3 were diagnosed preoperatively with unilateral vocal cord paralysis. After receiving accurate information about the possibility of worsening voice quality, all of the patients chose vocal cord lateralization instead of tracheotomy.

II. 1.2.1.2. *Surgical technique and postoperative care*

We used a modification of *Lichtenberger's* Type-A (later "reversible") endo-extralaryngeal suture technique (98, 99) for the vocal cord lateralization. We changed the original method in some aspects to be more reliable for the concept of "early" laterofixation adapting it to the physiological mechanism of the cricoarytenoid joint. The procedure is performed under general anesthesia. Trans-stomal intubation was carried out in patients with tracheostomy. In patients without tracheostomy a *Rüsch*-tube was introduced for trans-laryngeal intubation in our first four cases but we used the more reliable supraglottic *low-frequency JET ventilation* later. Earlier a *Kleinsasser,* later always a *Weerda* laryngoscope (Fig. 10. b, c) was used to open up the glottic space. The larynxes were exposed from the contralateral side of the vocal cord meant for lateralization, and the bivalve layngoscope is opened up slightly elevating the larynx from the posterior wall of the hypopharynx (Fig. 12. a). First, the cricoarytenoid joint mobility is examined by passive mobilization to of the vocal process during complete neuromuscular blockade. The vector of the agitating force is similar to the normal movement vector of the joint (X, XII). The vocal process is lifted up, and the arytenoid cartilage is pushed back by the tip of the *Lichtenberger's* needle carrier instrument (Fig. 10. a). Then a monofilament, non-resorbable thread (#2-0, or 0 Prolene) is passed under the vocal process out to the surface of the neck (Fig. 12. b). This action process is repeated by the other end of the thread above the vocal process by pushing backward slightly the arytenoid cartilage again (Fig. 11. a, 12. c). *The thread forms a loop around the vocal process then, permitting the creation of an almost physiological abducted CAJ position* (Fig. 11. b; 12. f). Moreover, the level of the abduction and -- thus the postoperative width of the glottis -- can be controlled by the endoscopist if JET ventilation is used for anesthesia or if the patient is intubated transstomally (Fig. 13. b, f) (X, XII). The external surgeon makes an approximately 5-10-mm-long incision between the two ends of the thread (Fig. 12. d, e), pulls back both ends under the skin with a *Jansen*-hook, and ties a knot above the prelaryngeal muscles (III, IV, VI, XVI) and not on the thyroid ala as was originally suggested by *Ejnell* (58) and *Lichtenberger* (98, 99). The incision is closed with one to two sutures.

Peri- and postoperative treatment: The patients received intravenous *Methyl-prednisolon-medrol* 250-500 mg before the surgery, the therapy was continued generally 250-500 mg twice-daily doses until the first or second postoperative day. A wide-spectrum antibiotic (parenteral *Cefuroxim* daily 2x750 mg) was used in the first 5 postoperative days (X, XII).

The reversibility of this concept means that, the lateralized vocal cord can return to its previous, generally paramedian position or normal movement, if the laterofixating suture is removed. This suture removal can be performed in local anesthesia from a small external approach in case of the vocal cord recovery of at least one side (Fig. 13. d) (XVI).

II. 1.2.1.3. *Spirometric measurements and follow-up*

The best result of three pre- and postoperative inspirations (forced inspiratory values during the 1st second (FIV-1)) were measured using an Electromedica MS-12 spirometer before the laterofixation procedure (15 patients) and on postoperative days 1 trough 5. The postoperative findings of 17 consecutive cases, in which the VCI remained permanent or the vocal cord movement recovery was incomplete over one-year follow-up were compared to the

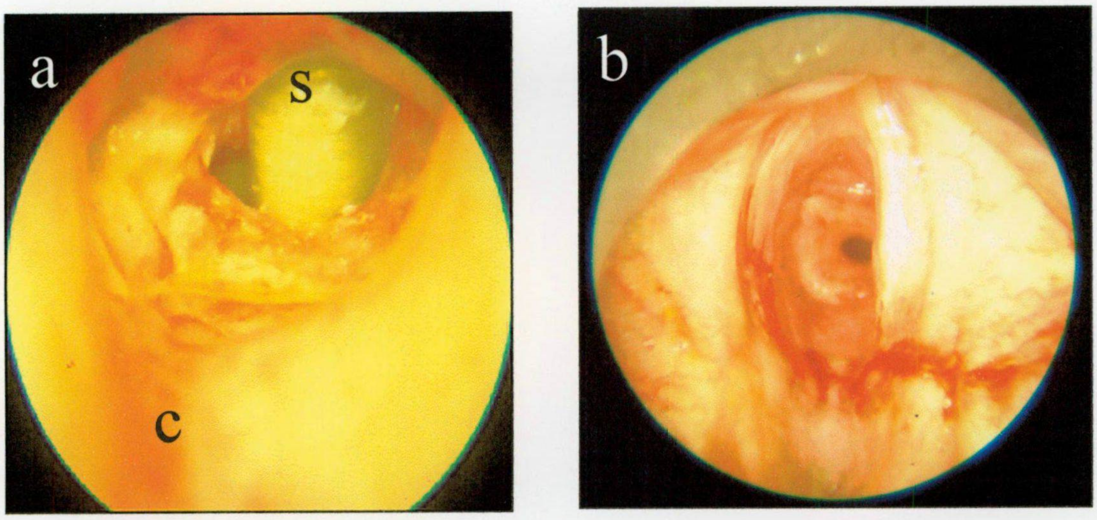

Fig. 9: **Development of a laryngotracheal stenosis after high tracheostomy**
a: scar formation in the level of the stoma made for an acut bilateral VCI. *c*: cricoid cartilage; *s*:stoma; **b**: The stenosis worsened six weeks later. The earlier laterofixed left vocal cord is in lateral position.

Fig. 10: **Special instruments**: **a**: Lichtenberger's needle carrier;
Weerda bivalve laryngoscope in closed (**b**) and opened (**c**) position.

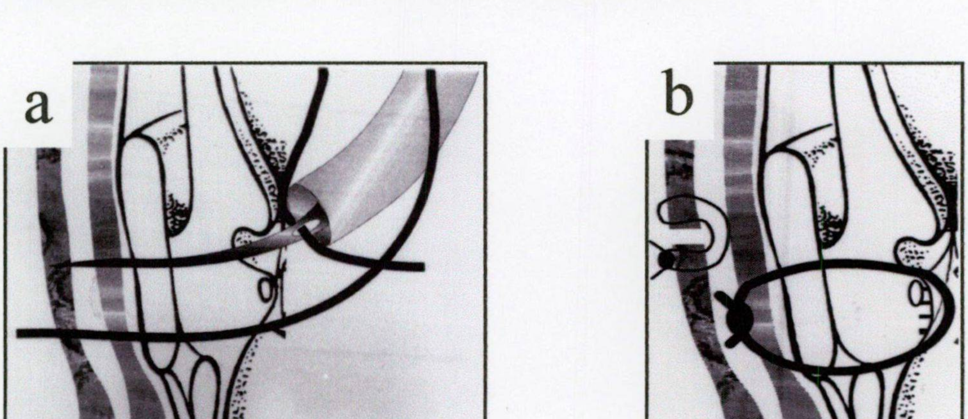

Fig. 11: **Sketch of vocal cord laterofixation**:
a: the two ends of a thread are passed under and over the vocal process **b**: the thread is knotted over the prelaryngeal muscles, thus it provides a lateral vocal cord position

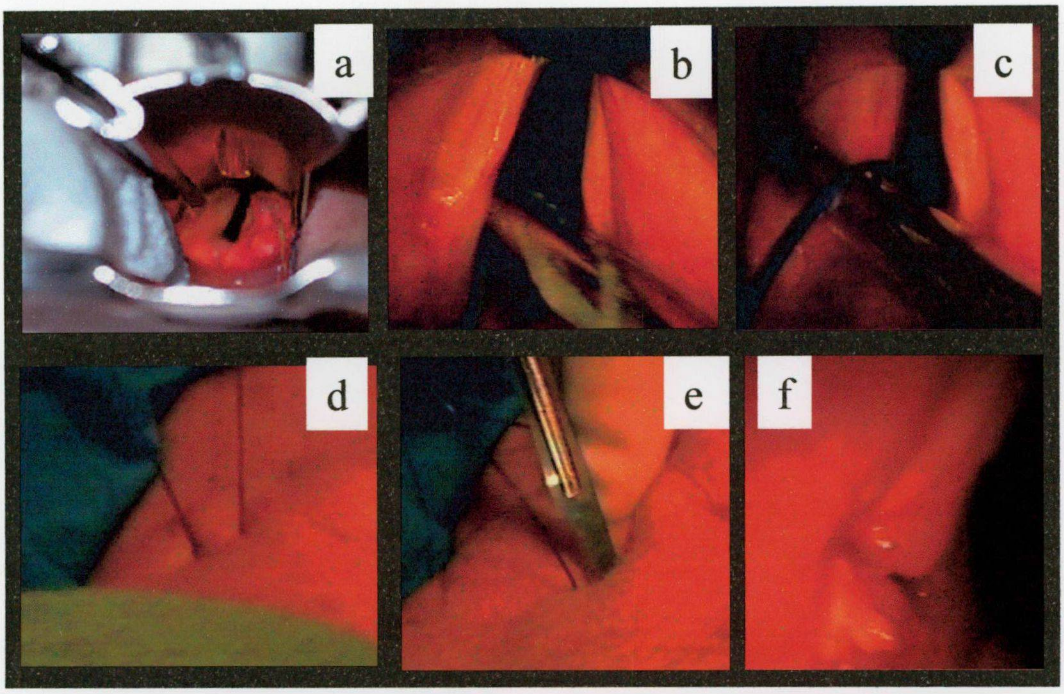

Fig. 12: Intraoperative pictures: **a**: approach via *Weerda* laryngoscope combined with JET-ventilation; passing the ends of the thread under **(b)** and over **(c)** the vocal process by the needle carrier; the thread is pulled back under the skin through a small incision **(d,e)**; the lateralized left vocal cord **(f)**.

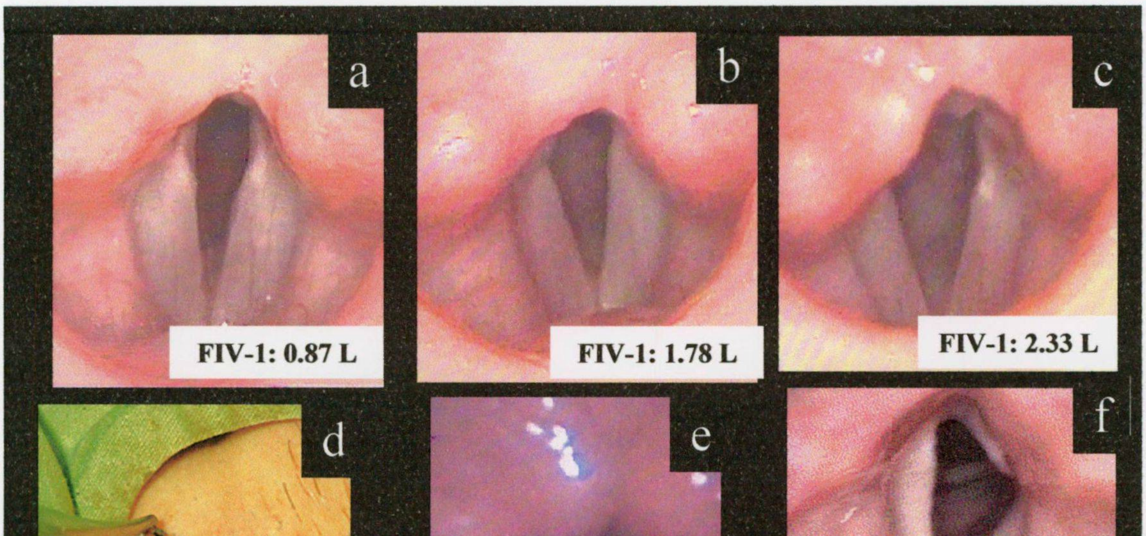

Fig. 13 : Results: bilateral VCI of a 27-year-old teacher **(a)**. the right vocal cord is placed in intermedier position (first postoperative month)**(b)**. the vocal cords recovered in the second postoperative month **(c)**. abduction of the right vocal cord is well recognizable in spite of the fixing suture. After the suture removal **(d)** the glottic closure and the voice completely recovered **(e)** (stationary stroboscopic photography). Left vocal cord of a 63-year-old woman is placed in full abduction **(f)** (6th postop. year).

result of the 12th postoperative month. Videolaryngoscopy (Storz-70^O optic) was conducted on each of the patients preoperatively and postoperatively from 2-week to 1-month intervals in the first year to detect vocal cord recovery as soon as possible. Radiological examination of the aspiration was performed in 15 patients at the end of the first postoperative month.

II. 1.3. *Results:*

II. 1.3.1 *Results within the first postoperative years*

Unilateral vocal cord laterofixation provided adequate airway in 39 patients (Fig. 13. b, f), and a bilateral laterofixation was performed successfully in two women with infantile-like larynx. They could be awakened without difficulties and the previous tracheotomies were closed immediately or within the 1st postoperative week. They had no dyspnea at rest and on moderate or usually on more serious physical exertion. Spirometry made on postoperative days 1 to 5 revealed approximately 110 % mean increase in FIV-1.0 in the cases without preoperative tracheotomy or intubation (Table II.) and it shows stability until the end of the first postoperative year in patient with permanent paralysis (Table III.).

Table II.: The change of FIV-1 values after the vocal cord laterofixation

n=15	**range**	**mean**	**SD**
Preop. (L/s)	0.4-1.2	0.78	0.26
Postop. (L/s)	0.8-2.2	1.51	0.42
Increase (%)	66-280	98	28

Table III.: The change of the postoperative FIV-1 values in the end of first year

n=17	**range**	**mean**	**SD**
postop	0.9-2.2	1.53	0.37
12nd month	0.9-2.3	1.57	0.48

Severe postoperative edema was found in four cases, but they could soon be managed conservatively without reintubation or tracheotomy. Only one 81-year-old man, who had been intubated previously for 4 days, had to undergo tracheotomy on the 3rd postoperative day because of edema resistant to conservative treatment. The extreme large resection because of a hypernephroma metastasis in the thyroid gland, the probable loss of the parathyroid glands (low Ca^{++} level: 1.9 mmol/L) and the wrong cardio-respiratory state might be responsible for the failure.

The thread cut into the substance of the vocal cord and the mucosa above it epithelialized approximately ten days following the surgery. Slight, approximately 1 mm, spontaneous vocal cord remedialization was observed in almost all patients without significant decrease of breathing in the first postoperative months. More significant medialization presented only in five cases in the first year. Two of these patients were operated on the side of the preoperatively diagnosed permanent VCI. In the third case the reason of medialization was probably due to technical failure, because the thread could not be passed through the thyroid ala in the proper place. Severe vocal cord medialization, when the vocal cord got back in paramedian position, was detected in the last two cases. The first one happened two weeks after the laterofixation procedure following kidney transplantation. After a repeated lateralization procedure on the same side breathing improved again. The intraoperative findings already revealed the ankylotic fixation of both cricoarytenoid joints in the second case. In spite of this, his breathing remained satisfactory at rest, because the contralateral vocal cord was not completely paralyzed.

Three patients exhibited aspiration later either clinically or radiologically during follow-up, and in one no further complication occurred. A 79-year old and a 75-year old women was tracheostomized because of repeated pneumonia caused by chronic aspiration in the seventh and the ninth postoperative month. They died in cardial failure in the first postoperative year.

However, the patients' dysphonia grew significantly worse after surgery, and their voices became more hoarse and weaker but generally well understandable. Some degree of vocal cord recovery was observed in 19 patients, but complete recovery followed only in 12 cases within 1 to 8 months after laterofixation. After a careful evaluation of breathing function, larynx size, and general condition, we decided to release the fixed cord in 11 cases. *In five cases vocal cord recovery happened only on the contralateral side of the laterofixation.* Four previously laterofixted vocal cords regained their preoperative paramedian position and one returned to an intermedier position from the previous maximal abduction usually within 2 weeks after the suture removal. *In four cases recovery was bilateral* (Fig. 13. c) *and in two cases only the laterofixated vocal cord recovered.* In five cases the previously lateralized cords regained their normal activities. Incomplete recovery presented only in one case after an 8-month period of laterofixation. Voice quality in these patients significantly increased in proportion to the medialization or recovery of the vocal cords (Fig. 13. e).

Five patients died from intercurrent disease (cancer: 3, cardiological problem: 1, pitfall in kidney transplantation: 1) within the first year. One patient was lost to follow-up, but she has been symptom free at the end of the first postoperative year according to information gained from her general practitioner.

II. 1.3.2. *Results over a year*

Of the 39 patient with adequate postoperative airway, taking into consideration the 11 cases of successful suture removal, the two tracheostomies due to aspiration, and the further 5 cases who died from an intercurrent disease *there were 21 permanent bilateral VCIs detected at the end of the first postoperative year*. Further significant spontaneous remedialization occurred later in four patients in the 15th, 17th, 22nd, 26th and in the 37th postoperative months. Two of these cases were probably the consequence of rupture of the laterofixing thread. In the third case medialization was detected after an inflammation presented around the suture. In two cases the exact causing factor remained unknown. Only three of these patients required repeated lateralization procedure, because in the other two cases the contralateral vocal cords partially regained their activities in the subsequent follow-up period. Summarizing the long-term results: *the early vocal cord lateralization has provided the definitive solution for adequate airway in **16 of 21** patients with permanent bilateral VCI* (Fig. 13. f).

II. 1.4. *Discussion*

The experimental results of the *endolaryngeal simple suture vocal cord lateralization* was published first by *Cancura* in 1969 (121). *Ejnell* published his exo-endolaryngeal lateralization technique in 1984 (122). Despite the theoretical simplicity, these methods were not accepted. According to *Tucker* (18), the major drawback of these procedures is that in many cases they do not yield adequate improvement. *Woodson et al.* (106) described these exo-endolaryngeal techniques as cumbersome and blind procedures with the general need of multiple attempts for precise suture insertion. *Lichtenberger* introduced his technique based on the same philosophy by his endo-extralaryngeal needle carrier instrument designed in animal experiences (97,98). Because of the uncertain, controversial results achieved on two patients (100,101) he developed and later applied the "EExLL" and the "EExLL" with arytenoidectomy techniques on further patients with excellent results (103,104) until 1998 (75).

In our new therapeutic strategy we introduced the modification of *Lichtenberger's* original "A technique" as an acut, potencially reversible solution of breathing insufficiency. We use a combination of supraglottic jet-ventilation and a bivalve *Weerda* laryngoscope (X, XII, XX), on which not only the angle of the blades can be adjusted, but also their proximal end distance. This approach allows a more precise thread insertion by *Lichtenberger's* needle carrier just around the vocal process or around the area of the short tendon of the vocal muscle inserted to the perichondrium in the lateral part of the arytenoid skeleton (123). According to our opinion, this provides a more stable surface for the thread than the membranous part of the vocal cord. The other important factor of success that *this approach allows the fixation of the arytenoid joint into the physiologically abducted position* (XIII, XX), which obviously causes minimal tension in the thread. These maneuvers can reduce postoperative medialization, similarly to the *King- Schobel* technique (87). In cases when the proper exposure of the glottis was impossible, - because of the anatomical situation, or the needle could not be passed through the proper place of the thyroid ala because of the often age related ossification - usually more significant spontaneous remedialization presented. A further advantage of proper suture insertion is that: the anatomical structure of the vocal fold remains intact; this is essential from the point of view of the expense of residual voice (XX) (95, 96, 112).

Animal experiments demonstrated that irreversible fibrosis occurs in the laryngeal muscles after 7 months of inactivation (74) leading to more-or-less severe fixation of the CAJ. We assume that the continuous tension produced by a fixed joint causes the fixing thread to cut through the vocal cord substance, which is mainly responsible for the failure of the late laterofixation procedures. Another important factor should be the increased synkinetic activity of the TAM in some cases. The fixation of the CAJ may lead to failure with the same mechanism, thus bilateral palsies registered after an upper airway inflammation must be evaluated with criticism. As one of our cases proves, suffocation may only be the manifestation of ankylosis (XII). In contrast, a mobile arytenoid cartilage can be easily rotated in the early period, an important fact in carrying out the vocal cord laterofixation procedure as soon as possible.

As concerns long-term effectiveness, whether the fixing thread cuts into the laryngeal tissues or the prelaryngeal muscles is highly significant. The use of a wider thread (Prolene-0 instead of the Prolene 2-0) also might play a role in the fact, that medialization decreased in most of the patients, as proven by the stable inspiratory values. The slight further increase of the average values at the end of the first postoperative year is probable the consequence of the partial vocal cord recovery and the improvement of patients' general condition (X). In our series the prelaryngeal muscles provide an appropriate flexible base for the fixing thread (III, IV, VI). Thus cartilage atrophy can be avoided, and the use of an external silicone platelet is not necessary (97, 98, 122). The access to the thyroid ala is not needed; therefore, in our experience the *entire operation takes approximately 10-15 minutes.*

At the beginning of this study the selection of the side to be operated on seemed to be a cardinal question (III, VI). We found in another group of patients, who suffered from posterior glottic stenosis (V, VIII) and were operated on using a similar lateralization technique, that laterofixed cord movement can be noticed by careful observation. The improvement of vocal cord abduction movement was detected in four patients in spite of the laterofixation sutures (Fig. 13. b, c) (X). Considering this we generally perform the procedure on the side, where the joint is more mobile in order to improve the long-term effectiveness if the paralysis turns out to be permanent (XII). Laryngeal electromyography (117) might also be a useful tool to detect this recovery in questionable cases. Obviously, a known, extensive nerve injury in the history clearly indicated the side of the laterofixation. Bilateral procedure is generally necessary rarely, only in case of infantile like women larynx.

The method is minimally invasive thus it can be carried out immediately after the previous thyroid surgery or even in elderly patients or those in precarious general condition in whom the briefness of narcosis has great importance. The generally moderate postoperative edema can be controlled effectively by using an intravenous and inhaled steroid combination, so an appropriate airway can be attained even in the first postoperative days (X). The endolaryngeal over-epithelization of the thread takes approximately 10 days, so the use of a wide spectrum antibiotic is suggested to prevent the spreading of bacterial infection from the larynx to the deeper layers of the neck. The postoperative period is easier for the patient and the hospitalization period is short, generally only 4-5 days.

Airway resistance decreases more than linearly by enlarging the diameter in the case of an upper respiratory tract stenosis. Other determining factors -- such as the narrowing effect of inspiration on the paralyzed glottis (*Bernoulli's* effect) and turbulence -- also decrease concurrently with the deceleration of the flow (124). Therefore, the relatively smaller enlargement of the glottis leads to a significant decrease in laryngeal resistance. Supraglottic JET ventilation provides an excellent evaluation of glottic diameter; thus, it becomes possible during surgery to determine individual glottis width (depending on the patient's larynx size, cardiorespiratory condition, profession, etc.). Thus the postoperative voice of our patients became weaker - in inverse proportion to the adequacy of the airway achieved - but socially acceptable in most cases (X). *Ejnell et al.* (122) reported similar findings. The other factor of the good postoperative voice can be the preservation of the intralaryngeal neural network and muscular system (II) compared to that surgical interventions, which destroys the cricoarytenoid joint unit. These structures, normally probable with only additive function, may provide spontaneous improvement of the voice rehabilitation in the later phase of the paralysis.

Clinical observation demonstrates that temporary laterofixation of the vocal cord is possible without causing any lasting damage if the thread is removed within 10 weeks (58). In our series, the patients' voice improved due to more or less overcompensation at phonation after the recovery of the contralateral cord mobility. In cases where the fixing thread was removed, the vocal cord position became more medial (X). This might happen even 2 years after surgery causing further improvement in voice as proven by one of our patients (XII). The small phonation gap, which remained at the site of the suture in the posterior glottic chink, had no significant influence on voice quality (Fig. 13e). According to the patients, almost complete restoration of preoperative voice was achieved when recovery was bilateral. In the case of a late (more than 6-8 months) vocal cord deliberation the immediate results might not be so impressive as proven by one of our patients. Muscle fibrosis (74), development of pathological voice production (false vocal cord phonation etc.), and only partial reinnervation may have played a role in this case. Speech therapy was effective, but this fact suggests the necessity of removing the fixing suture as soon as possible. In the case of a patient with a small larynx and with poor cardiorespiratory condition or only partial vocal cord recovery, the mobilization of the fixed cord must be evaluated individually. The preservation of the arytenoid cartilages ensured the good false-vocal cord phonation in 4 cases of permanent VCI (27).

Most of our patients were able to return to their previous lifestyles after a short period of time without difficulty. Generally, there were no significant complaints as concerns swallowing. The intact mucosa and sensorial innervation of the larynx and the preservation of the laryngeal inlet anatomy can probably explain the absence of aspiration (95, 96). Similar experience was reported by *Geterud et al.* (125). On the other hand, in case of an elderly patient with swallowing problems the laterofixation must be thought over.

II. 2. **Minimally invasive surgery for posterior glottic stenosis**

II. 2.1. *Introduction*

The posterior glottis consist of the posterior third of the vocal cords, the posterior comissure with its IAM, the cricoid lamina, the CAJ, the arytenoids, and the overlying mucosa. Posterior glottic stenosis (PGS) most commonly results from *prolonged endotracheal intubation.* The tube causes decubitus (Fig. 14. a, b), and the secondary infection results in perichondritis with consequent formation of scar tissue, which often limits the movement of the arytenoid cartilage leading to cricoarytenoid joint fixation (Fig. 14. c). The glottic obstruction results in severe inspiratory dyspnea, and most patients with this problem are tracheostomy dependent and have compromised vocal function. *Whited* (59) found a 1 % incidence of postintubation glottic stenosis in 200 patients after prolonged intubation. In case of an intubation lasting more than 10 days, the incidence is higher; it can increase up to 14 % (126). The other factors that contribute to the increased risk for stenosis following intubation include traumatic intubation, large tube size, motion of the endotracheal tube and local infection (59, 126, 127).

Prior to the widespread use of prolonged endotracheal intubation the incidence of PGS was low and generally due to abnormal sixth branch development (128), infectious etiologies, external trauma, inhalation of caustic ingestion (126, 127, 129, 130). Nowadays PGS has been associated with other iatrogen factors, surgical interventions in the posterior glottic area, such as treatment of recurrent papillomatosis or failed treatment of bilateral VCI (27, 105, 127) etc. PGS can develop after laryngeal irradiation (131) as in one of our cases, after the irradiation of a laryngotracheal adenocarcinoma. The diagnosis is generally based on direct laryngoscopy and passive mobilization of CAJ (118), but neuromyography would be a helpful tool in the differentiation from the paralytic causes (117,132).

There are 4 degrees of stenosis according to the *Bogdasarian and Olson* (133) classification: type I, the scar is located between the vocal processes(Fig. 14 c); type II, the posterior commissure is invaded by the scar tissue (Fig. 18 a); and type III, IV, glottic stenosis is present and involves 1 or both cricoarytenoid joints (Fig. 17. a).

Many different endolaryngeal or extralaryngeal procedures have been devised to solve the problem of stenosis (Fig. 15. a-d). The applied method depends on the degree of the stenosis and the experience of the surgeon. The treatment modalities for PGS can be classified in the following categories: *percutaneous intralaesional* steroid injection (134); *endoscopic* *incision* by microsurgical instruments or CO_2 laser (135); endoscopic submucosus (136) or transverse cordectomy (137); CO_2 laser microtrapdoor flap (138); endoscopic scar incision and stent insertion with endo-extralaryngeal fixation (131,132); *endoscopic arytenoidectomy with stenting* (106); *external scar incision* with *keel* (139) or *local flap* (127, 140); *Réthi-type laminotomy* (76, 141, 142) *with or withot arytenoidectomy* (131).

One of the disadvantages that even the most successful procedures share is that temporary tracheostomy might have to be sustained for an extended period of time. Since 1995 we have introduced a new treatment modality, which has given good functional results and spares patients from a tracheostomy (V, VIII, XVI).

II. 2.2. *Patients and Methods*

II. 2.2.1. *Patients*

Fourteen consecutive patients (8 women and 6 men) were operated for PGS from August 1995 to August 2002. Ages of the operated patients ranged from 15 to 62 years, average 40 years. The follow-up period was minimum six months. *In 10 cases the PGS developed after prolonged intubation. Failed unilateral or bilateral arytenoidectomy* was the causing factor in two patients. The PGS developed after *external neck trauma* in another case, and after *irradiation of a laryngotracheal tumor* in the remaining patient. Only this patient was tracheotomised at admittance to our clinic. There were one type I, four type II, two type III and seven type IV stenosis according to the *Bogdasarian-Olson* classification. In eleven cases the stenosis was isolated and in 3 patients the PGS associated with severe laryngotracheal stenosis.

II. 2.2.2. *Surgical technique and postoperative care*

The procedure (Fig 17) is performed with the patient under general anesthesia, and a *Rüsch* tube is introduced for intubation or Jet ventilation anesthesia. Earlier a *Kleinsasser*, lately always a *Weerda* laryngoscope was used to expose the posterior glottic space. The scar is excised by CO_2 laser, without touching the postcricoid mucosa (Fig. 17. b). The mobility of the cricoarytenoid joint is examined with passive mobilization (118), and the classification of the stenosis is established according to *Bogdasarian and Olson* (133). In case of a fixed joint, the arytenoid cartilage is moved with a *Magill* forceps, following the direction of the joint's physiologic movement as described by *Johannsen and Wallesch* (143) and as our study proved (XIII). In the cases of severe stenosis, when reoperation is necessary a more extensive scar mobilization is performed with the opening of the cricoarytenoid joint via antero-medial aspect by CO2 laser.

The cardinal part of the procedure is the laterofixation of the vocal cord or cords with our modification of *Lichtenberger's* method, similarly to the way described in chapter **II. 1.2.1.2** (Fig. 17c). Application of this procedure after the excision of the scar tissue and laterofixation of the vocal cord or cords allow the wound sites to be held apart from each other until the reepithelialization of the posterior glottic area (Fig. 16, 17c). In two cases, when the PGS associated with tracheal stenosis the vocal cord laterofixations were performed before the successful tracheal resection, and in the third case laterofixation was performed in one step with tracheal resection.

When reepithelization can be confirmed by laryngofiberoscopy, the fixing sutures can be removed through the skin incision. In the case of a bilateral laterofixation, the sutures are removed with about a month's difference, when the first released vocal cord motion is recovered. The fixating sutures were not removed in those cases when the stenosis developed after arytenoidectomy or the scar deeply involved the cricoarytenoid joint

Peri- and postoperative treatment: The patients received intravenous *Methyl-prednisolon* 250-500 mg before surgery, the therapy was continued usually 40-500 mg twice-daily doses until the first or second postoperative day. A wide-spectrum antibiotic (*Cefuroxim* 500-250 mg two times daily) was used in the first 5 postoperative days.

II. 2.2.3. *Follow-up examination and documentation*

The patients had monthly follow-up examination by laryngofiberoscopy. Breathing functional tests were performed on an Electromedica MS-12 spirometer. The best of three inspiration values was measured. The forced inspiratory volume during 1 second (FIV-1) was documented first before and after the laterofixation procedure, then monthly, and finally before and after the laterofixation sutures were removed.

II. 2.3. ***Results*** (Table IV)

In our first case, a 21-year–old woman had a 3-day prolonged intubation history that resulted from a diabetic coma. A month later she was admitted to our clinic with progressive

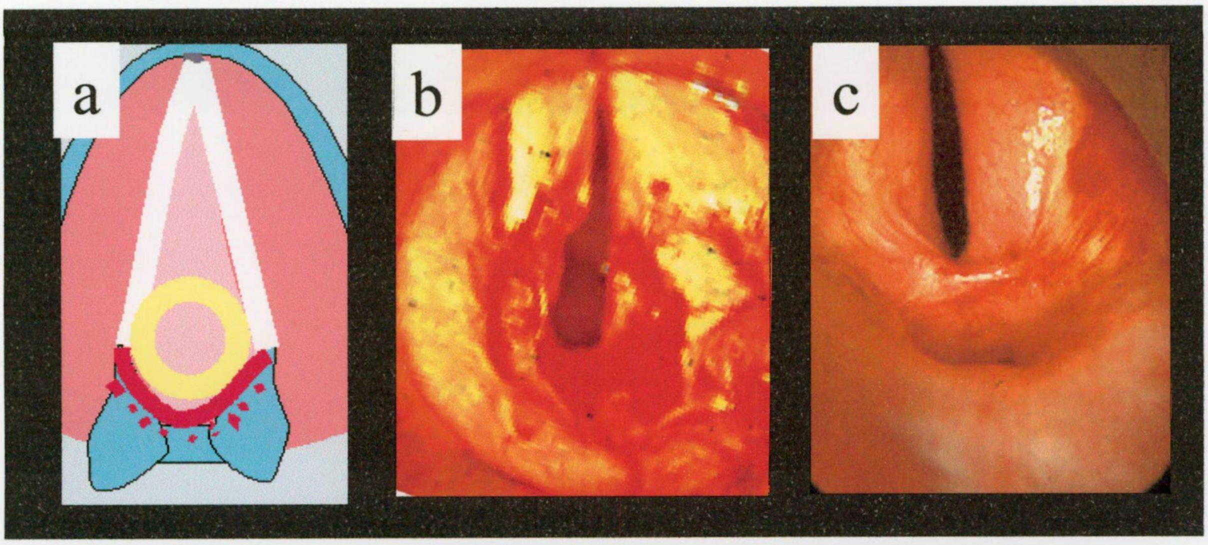

Fig. 14: Development of posterior glottic stenosis after long-term intubation. a: The tube causes infection and exulceration; **b**: decubitus in the posterior commissure; **c:** type-I stenosis

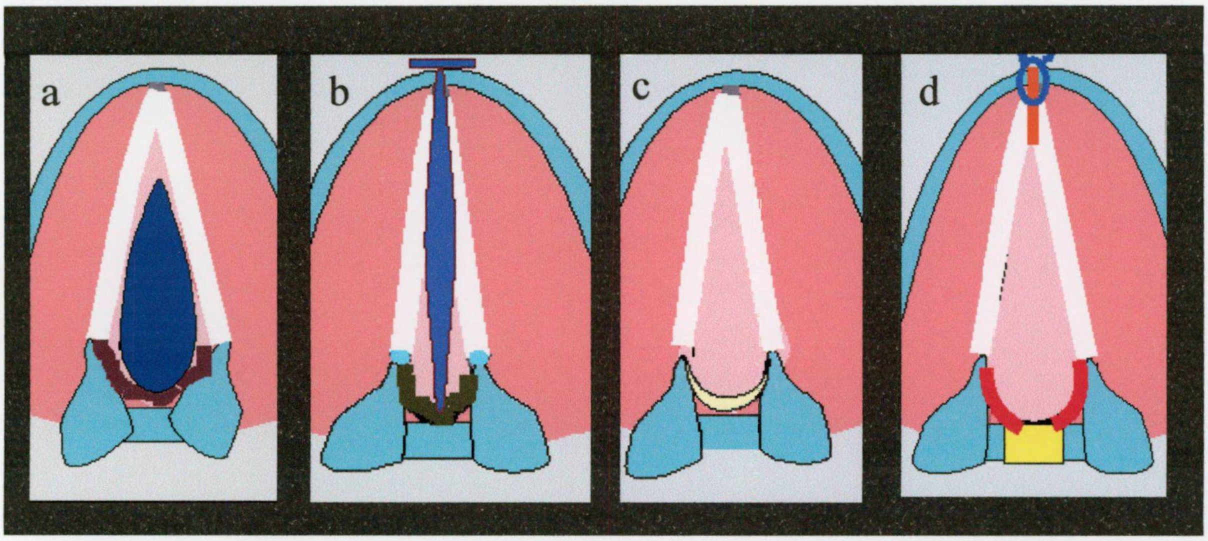

Fig. 15: The basic types of surgical procedure to prevent restenosis after scar excision. **a**: stent; **b**: keel; **c**: covering of the wound by mucosa, skin etc.; **d**: Réthi-type posterior laminotomy and interpositum

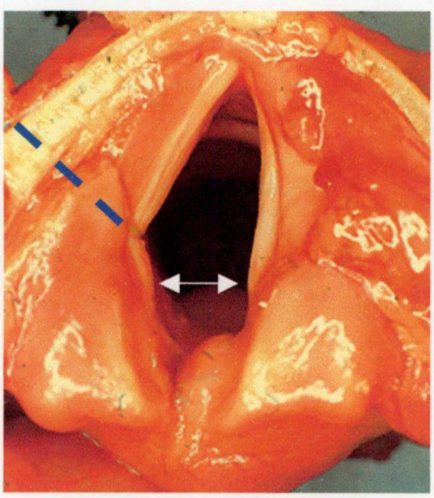

Fig.16: Our method: to keep away the wound surfaces by temporary vocal cord laterofixation. The achievable wide distance in the posterior commissure is demonstrated on a cadaver human larynx. The left vocal cord is laterofixated. The supraglottic part of the larynx is removed. The blue line shows the situation of the fixing thread.

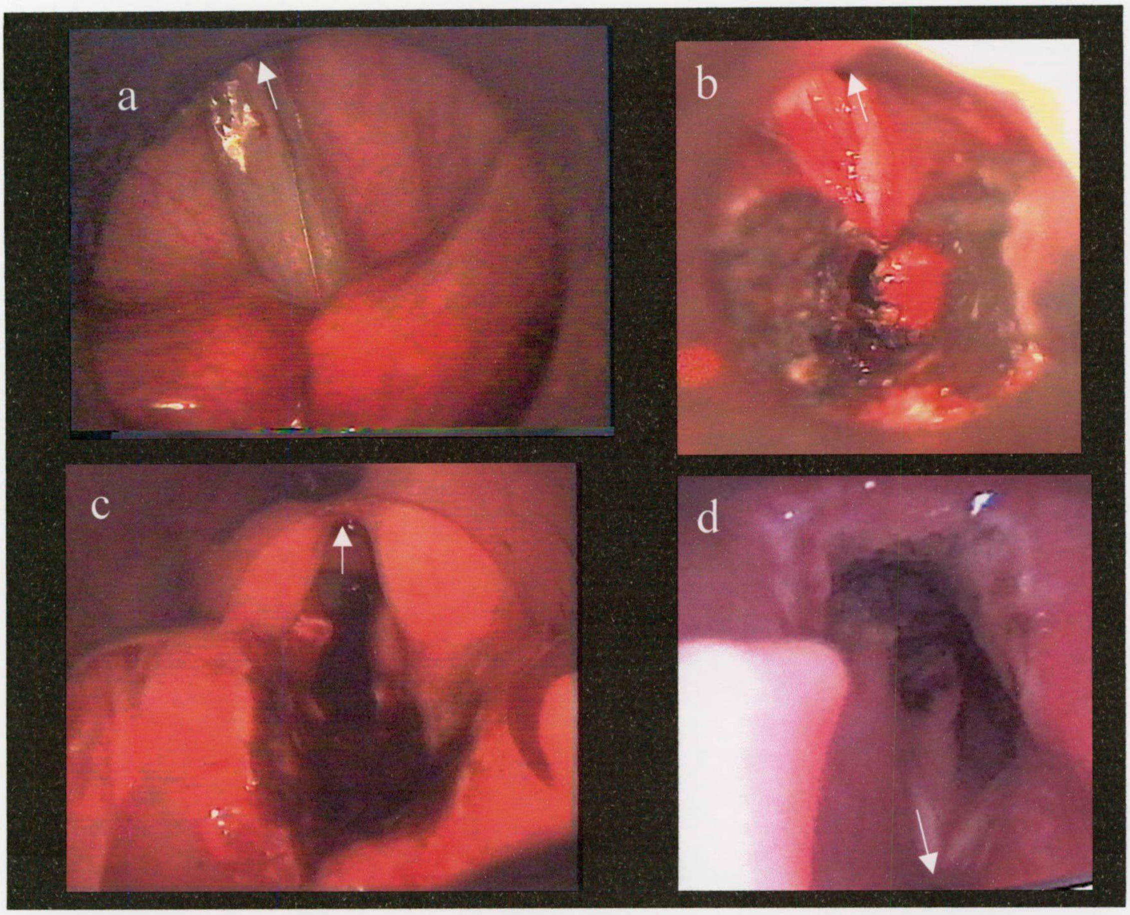

Fig. 17: Intraoperative pictures. a: type-IV stenosis; **b**: CO_2-laser excision of the scar; **c**: both vocal cord is lateralized under the false vocal cord; **d**: the wide glottis on the second postoperative day; *white arrows* point to the anterior commisure

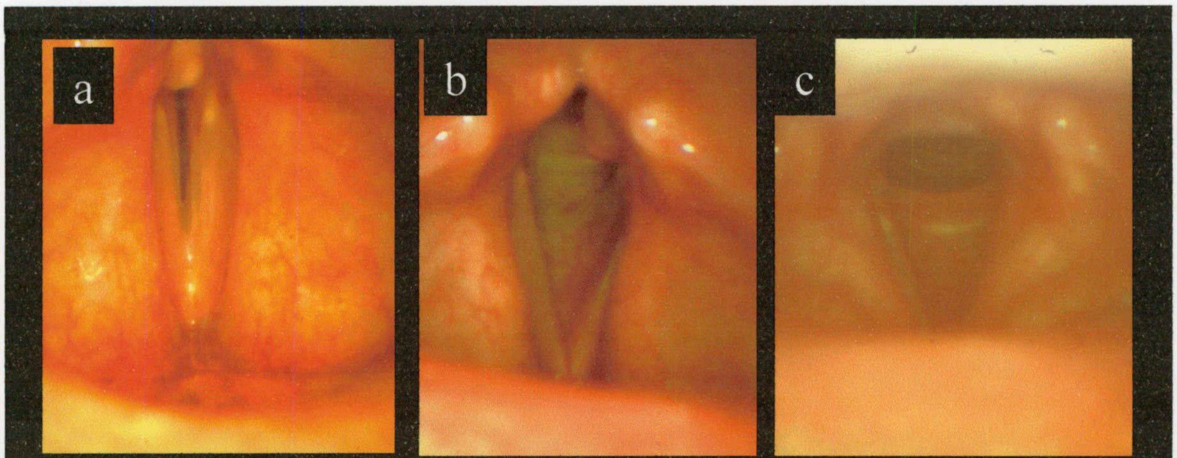

Fig. 18: Results: a: Type-II stenosis of a 28-year-old man; **b:** The glottis is wide 4 weeks after the left vocal cord laterofixation. A mild granulation can be seen in the posterior commissure; **c**: vocal cord movements recovered after suture removal, there is no scar in the posterior commissure (the picture was made six month after the procedure).

dyspnea and inspiratory stridor. Type II posterior glottic stenosis was diagnosed. The width of the glottis was 2 mms. The glottic scar was excised by CO_2 laser in the middle. One month later the dyspnea developed again. The glottis was 1 mm wide (FIV-1, 0.8 L) as a result of the repeated type II scar formation in the posterior commissure. After laser scar excision, the left vocal cord was laterofixed. Right after the procedure the glottis became sufficiently wide (FIV-1, 1.65 L). The movement of the right vocal cord was recovered within a month (FIV-1, 2.75 L): Although the patient did not agree to removal of the laterofixation suture for years, her voice has become socially acceptable because of the overcompensation of the right vocal cord. Eight years later (!), her voice improved significantly after the removal of the fixing suture was removed.

All the other patients' glottis became adequately wide right after the surgical procedure (Fig. 17. d, 18. b), nevertheless, in six cases the intensive antiedematic conservative treatment continued approximately for a week. The preoperative FIV-1 values generally increased more than 100% (Tabl.: III). In cases, when the vocal cord laterofixation was performed with mobile joint (Type I-II-III), and the fixating thread were removed, good vocal cord recovery were detected (Fig. 18 c) (patient 1, 2, 3, 6, 13, 14), and their voice were similar to the quality of their natural voice according to the patients, but sometimes remained slightly hoarse, as a result of a mild phonation closure insufficiency as the site of the suture. They could soon return back to their previous life-style generally.

In cases when the PGS associated with bilateral joint fixation functional results showed more or less significant decrease in the long run. In the first two patients in this group reoperation were necessary after the removal of the fixating thread. For this reason, in case of a fixated joint we have avoided suture removal, moreover we introduced a more extensive scare incision with the antero-medial opening of the joint from antero-medial aspect later. This modification diminished the decrease of breathing values (patient 4,5,12). This method could also be applied well when surgery was associated with tracheal resection (patient 7, 10, 11). These patients' voice remained hoarse, breathy, but socially acceptable.

When the PGS developed after a failed arytenoidectomy, the breathing values improved after surgery, and the fixating sutures were not removed, because function recovery couldn't be expected in these cases.

During the first 3-5 postoperative days the aspiration spontaneously ceased in all cases.

Table: IV.: Patients with posterior commissure stenosis and their postoperative outcome

patient	age/sex	etiology	type of stenosis	type of surg.	suture rem.	FIV-1 (L) preop.	FIV-1 (L) postop.	FIV-1 (L) 1^{st}y.	rvcm
1	21/w	lt int.	II	si	-	-	-	-	
	Reop			si+ lf l.s.	+ (S)	0.80	1.65	2.75	both
2	29/m	lt int.	II	si+lf l.s.	+ (s)	-	3,25	3.65	both
3	49/w	lt int.	III	si+lf l.u.	+(r)	0.70	1.65	2.20	right
4	62/m	lt int.	IV	si+lf l.u.	+(u)	1.23	2.43	1.50	-
	Reop			esi+lf .u.	-	1.50	2.60	2.1	-
5	17/m	lt int.	IV	si+lf l.u.	+(r)	1.20	2.15	1.45	-
	Reop			esi+lf l.u.	-	1.45	2.30	1.90	
6	39/w	lt int.	II	si+lf l.u.	-	0.85	2.60	3.10	both
7	16/w	lt int.	IV+trach. sten.	esi+lf l.u.+tr	-	1.10	2.35	1.90	-
8	62/w	st. p. arytenoidect.l.d	III	si+lf l.u.	-	0.60	1.80	155	-
9	59/w	st. p. arytenoidect.l.u	IV	si+ lf l.u	-	0.50	1.90	1.45	-
10	53/m	external trauma	IV+trach. sten.	esi+lf l.u.+tr	-	1.45	2.20	1.90	-
11	42/m	st.p.cricotrac. tu. irrad.	IV+trach. sten.	esi+lf l.u.+tr	-	trach.	2.55	3.10	
12	62/m	lt int.	IV	esi+lf .l.u.		0,60	2.35	1.85	-
13	37/w	lt int.	I	si+lf l .s.	+	0,70	1.90	2.55	both
14	15/w	lt int.	II	si+ lf l.u.	+(u)	-	1.90	2.90	both

1^{st} y.: at the end of first postoperative year; *esi*: extended scar incision; *lf*: vocal cord laterofixation; *l.r.*: right side *l.s.*:left side; *lt int*: long-term intubation; *l.u.: bilateral*; *m*: man; *trach.*: tracheostomy; *tr*: tracheal resection; *trach. sten*: tracheal stenosis; *si*: scar incision; *suture rem.*: suture removal; *rvcm*: recovered vocal cord motion; *w*: woman

II. 2.4. *Discussion*

The innervation of the vocal cords is generally intact in the case of a posterior glottic stenosis, thus theoretically a full recovery of glottic function can be expected after surgery. Nevertheless, the simple excision of the scar tissue is usually insufficient for the reestablishment of glottic function. *Cohen* (135) reported only 3 successful decannulations in 7 patients who underwent endolaryngeal laser scar tissue vaporization. The above statement is also supported by our first case where the simple scar excision led to only temporary success (V, VIII). The vocal cord stays in the paramedian position for days after the scar transsection, and the complete return of the abducting movements might take weeks (59) – as the nonlaterofixated vocal cords demonstrated in our cases too – allowing for the repeated development of adhesions. The essential step in the various surgical techniques is the prevention of contact of the denuded wound sites after scar excision or vaporization. These methods, both endolaryngeal and extralaryngeal procedures, require temporary tracheostomy or cause irreversible severe decrease of voice quality. Our suggested procedure avoids these disadvantages. By the temporary vocal cord laterofixation the translaryngeal airway becomes free immediately after the procedure, as occurred in all of our patients. In the case of our 3 patients (with type I-II stenoses) the unilateral laterofixation was successful. In our opinion, in cases of type III-IV stenosis, when arytenoid fixation occurs, the necessary distance between the operated sites could only be achieved in case of bilateral vocal cord lateralization (V, VIII). One of the great advantages of our surgical technique is that the wound surfaces can be kept apart for a longer period, until healing is complete. In our experience the minimal period for laterofixation is approximately 6 to 8 weeks because this is the duration of the complete mucosal reepithelization after laser glottic surgery (116).

When the lateralization is suspended, the innervated vocal cord movement can be reestablished even after a longer period, hence, with a narrow (female) larynx we recommend the temporary bilateral vocal cord laterfixation, even in cases of type I or II stenosis (V, VIII). Nevertheless, considering the reversibility of the laterofixating procedure bilateral fixation is also considerable in all of these cases to improve the distance of the vocal processes. The good functional outcome is provided by the almost complete vocal cord recovery after the removal of the laterofixation sutures in these cases, thus normal voice quality can be expected after the procedure.

According to our opinion complete vocal cord recovery in cases of a fixed CAJ cannot be expected. The affected vocal cords remain fixed but in a bit more lateral position. The same results can be expexted, if the stenosis developed after failed arytenoidectomy and the vocal cords are paralyzed. Thus, in order to improve the long–term results from the view of breathing; the fixing thread is not suggested to be removed (VIII). The opening of the capsule of the CAJ improves the effect of vocal cord laterofixation (105).

The temporary mild aspiration generally lasts for only a few days, because of the spared laryngeal sensorial innervation and the integrity of the laryngeal inlet.

II. 3. Vocal cord lipo-augmentation for the phonosurgery of unilateral vocal cord paralysis

II. 3.1. *Introduction*

Unilateral vocal cord paralysis (Fig. 20. a, 21. a), vocal cord atrophy, vocal cord bowing etc. may lead to incomplete closure of the vocal cords during phonation. The voice may tire soon, become more or less hoarse, weak or sometimes whispering. In the first place *speech therapy* is the generally accepted way of treatment, and surgical procedures can be applied when it had been proven to be unsatisfactory. In this part, in accordance with the concept of the thesis I focus on the problem of unilateral vocal cord paralysis.

The surgical procedures can be divided in to three groups: 1. the endolaryngeal vocal cord augmentation first by paraffin (144), later by Teflon (145), or nowadays by autologous fat (146); 2. the external laryngeal framework or thyreoplastic surgeries (147, 148, 149); 3. the reinnervation procedures (18, 150, 151). Recently the augmentation procedures have been widely accepted, because they provide good phonatory results with relatively easy surgical technique. Nowadays Teflon is the most frequently used filling material, nevertheless the decades of its use have pointed out some disadvantages and possible side effects. Teflon might migrate far in the body (152), it can provoke foreign body reaction; moreover it causes vocal cord rigidity and irregularity of its edge because of the scarry capsule developed around the injected material (153).

Autologous fat has been used since the end of the 19th century for free transplantation, but *Mikhaelian et al* (146) reported for the first time about the endolaryngeal vocal cord augmentation in literature in 1991. In our clinic we have used this procedure for the treatment of unilateral vocal cord paralysis since 1996 as the first institute in Hungary and one of the first in Europe (VII, IX, XV, XVIII). In spite of the new materials that have been suggested so far, as collagen (154), Gore-tex (155) etc. autologous fat remained the routine material in our institute.

In this study we examined the clinical applicability of our surgical modifications in the technique of vocal cord augmentation and of the autologus fat as one of the most physiological filling material.

II. 3.2. *Patients and Methods*

II. 3.2.1. *Patients*

Sixteen consecutive patients (12 women and 4 men) were operated for unilateral VCI from August 1996 to August 2002. Ages of the operated patients ranged from 26 to 56 years, average 37 years. The follow-up period was minimum six months. In 12 cases the RLN paralysis developed after thyroid surgery, in two cases the vagal paralyses developed after the removal of an acoustic neurinoma from suboccipital approach. In two cases etiology remained unknown. In thirteen patients the paralized vocal cords were in paramedian, and in three cases in intermedier position. All patients were operated minimum six months after the onset of the paralysis and in these cases the preoperatively applied speech therapy had not provided satisfactory results.

II. 3.2.2. *Surgical technique*

In our first patient the general anesthesia was performed with *Rüsh*-tube intubation all along the surgery. Later we have changed it to a combined narcosis technique (Fig. 19.). Surgery was performed in total intravenous anesthesia using *Propofolol* 2 mg/kg in bolus continued 6mg/kg/h by perfusion pump combined with ultra short-term myorelaxant (Norcuron 35 mg/kg) used for controlled myorelaxation (Train of four (TOF)-guard system). Intubation narcosis remained for the fat harvesting procedure, but the endoscopic augmentation procedure was performed by low-frequency JET-ventilation.

The abdomen was sterilely prepared and approximately 5 cm^3 fat was gently surgically harvested from the left trochanter subcutan area through a 1 cm incision. The fat tissue was diced by scissor removing any fibrous tissue and put in a 5 cm^3 injection container. Then it was passed trough a 19-gauge needle into a 2 cm^3 injection container what was used for the augmentation. Those pieces that could not be passed easily trough the needle were removed.

In the first patient a *Kleinsasser* laryngoscope, later a bivalve *Weerda* laryngoscope was used to open up the larynx (Fig 20. a). The laryngoscope was led into the larynx from the midline in order to achieve the best evaluation of real vocal cord position. The posterior valve of the laryngoscope was placed behind the arytenoid area into the hypopharynx, the anterior one was inserted over the anterior commissure. Then by the gentle opening of the valves the larynx was lifted up from the posterior wall of the hypopharynx making the free mobilization of the cricoarytenoid joint possible. The fat was injected in two steps into the vocal cord.

The first bolus was placed beside the vocal process to push it to the midline (Fig. 20. b, c; 22. a, b), and then the second bolus was injected in the intermedial third of the vocal cord as close as possible to the thyroid ala to correct the contour of the vocal cord (Fig. 20. d; 22. a, b). Counting with some spontaneous fat absorption in the long run approximately 20-30% volume overcorrection was applied. The protective laryngeal reflex could be evoked by the mechanical irritation of the glottis due to the short-term myorelaxant in this phase of the surgery (the relaxation level is less than 20 percent), therefore the expectable closure of the glottis could be estimated and could be corrected during the surgery (Fig. 20. e, f). A wide-spectrum antibiotic (cefuroxim 500-250 mg two times daily) was used in the first 5 postoperative days in order to prevent the infection and the consecutive absorption of the free transplant.

II. 3.2.3. *Postoperative measurements and follow-up*

Videolaryngostroboscopy

The glottal closure and the mucosal waves were evaluated during the production of sustained "i" with normal pitch by pre- and postoperative videoendoscopic (Storz-70^{0} optic) (Fig. 21. a) and laryngostroboscopic examinations (*Storz laryngostrobe*) in each patient and it was recorded to SVHS videotape. The examinations continued usually monthly in the first six postoperative month and at the end of the first postoperative year.

Histological examinations

Trypan blue supravital staning (152) was performed in five patients' prepared fat in order to prove the presence of viable adypocytes in the transplanted material. Tripan blue will stain dead or dying cells. Viable cells are able to repel the dye by pinocytosis and do not stain.

Hematoxilin and eosin staining was used to prove the presence of the transplanted fat tissue in a 58-year-old man's larynx. This case was not the member of the series but the chronic severe aspiration was the indication for vocal cord augmentation after a supraglottic laryngectomy combined with tongue-base resection because of cancer. The procedure had no satisfactory result in the long run, thus total laryngectomy was performed a month later.

Magnetic resonance imaging (MRI): The long-term survival of the fat tissue was demonstrated in 4 patients in the first, in the third, in the sixth and in the tenth postoperative month by T1 weighted images.

Phoniatrical examinations

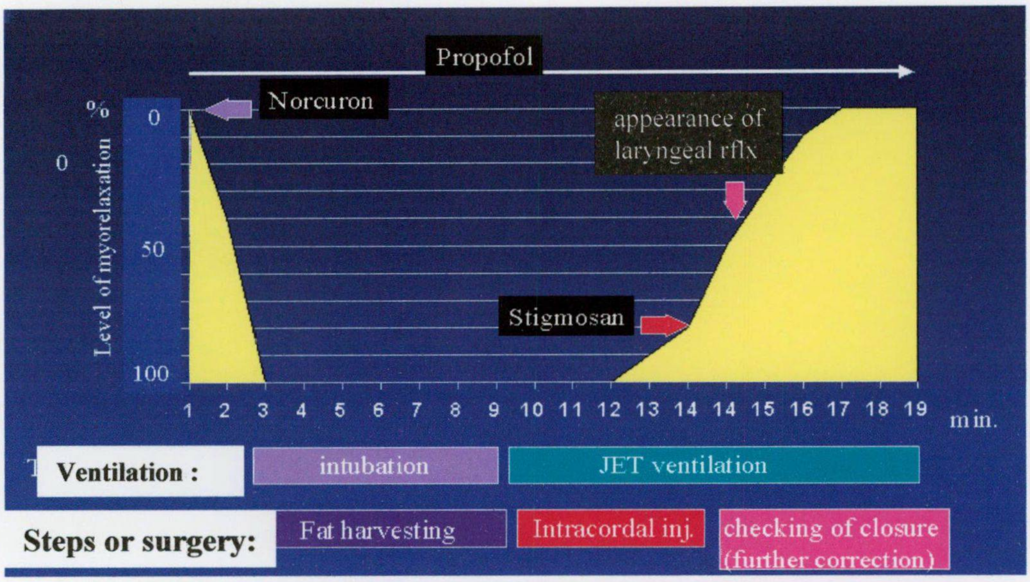

Fig. 19: Sketch of the anesthesia and the surgical procedure

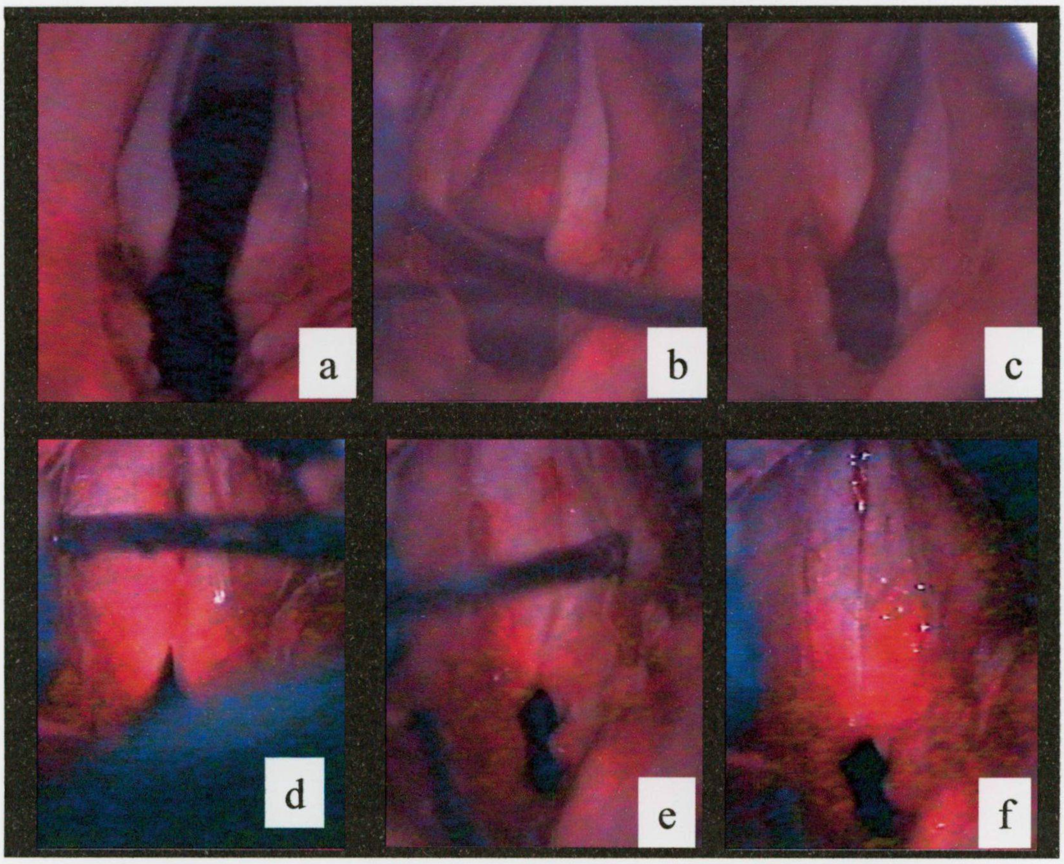

Fig: 20: Intraoperative pictures of lipo-augmentation. The left vocal cord paralysis associated with bilateral vocal cord bowing in this case, thus well represents the possibility of the correct surgical adjustment by this method.
a: paralyzed left vocal cord in intermedier position; **b,c**: medialization of the vocal process by the first bolus of fat; **d**: correction of the vocal cord contour by the second bolus of fat placed in the middle of the membranous part; **f**: after the closure of the vocal cords (protective laryngeal reflex!) further correction can be made in the atrophized right vocal cord; **g**: the glottic closure is perfect after the surgery.

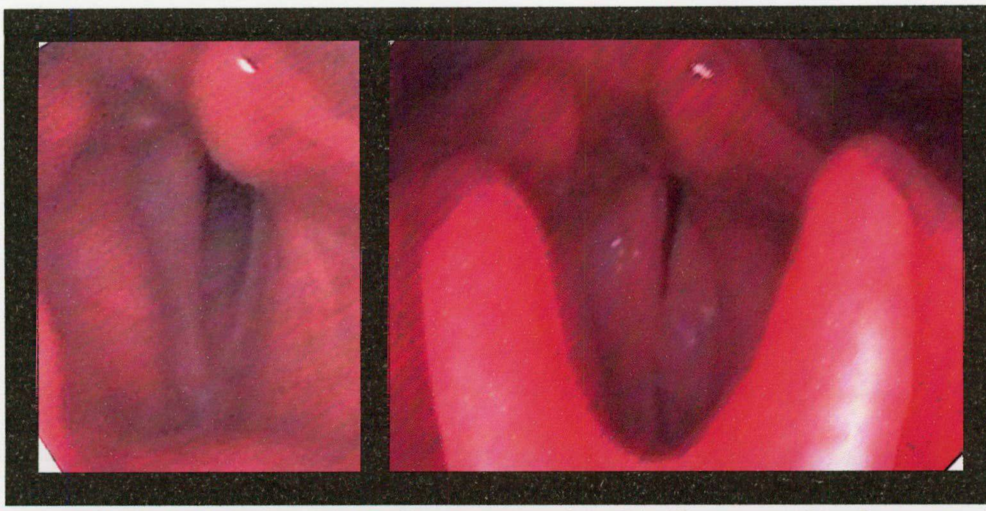

Fig: 21: Preoperative (a) and postoperative (b) (first month) photograph of the same patient (fig. 20) during phonation made with 70° Storz endoscope

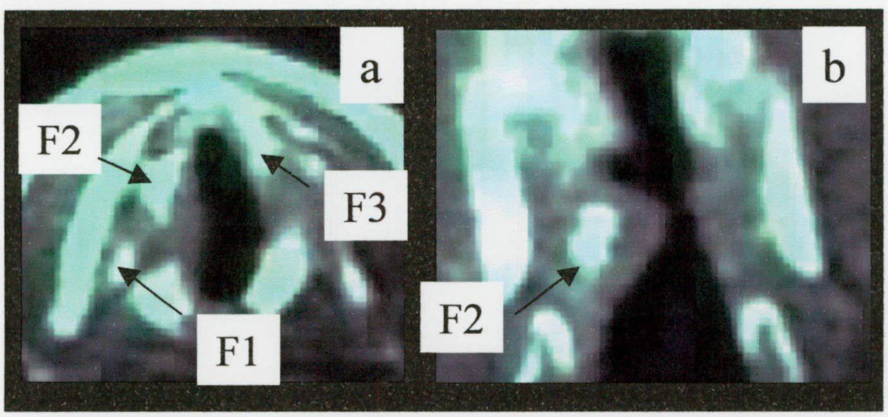

Fig 22: Axial and coronal T1-weighted MRI pictures in the 6th month.
Fat signals appear as light areas in the mass of the vocal cords. **F1:** first bolus and **F2:** the second bolus on the left side.; **F3**: third bolus on the right side.

Fig. 23: Long-term result. a: phonation after left vocal cord lipo-augmentation in the second postoperative year; **b**: MRI in the 10th postoperative month. Blue arrow shows the white area of the transplanted fat in the vocal cord

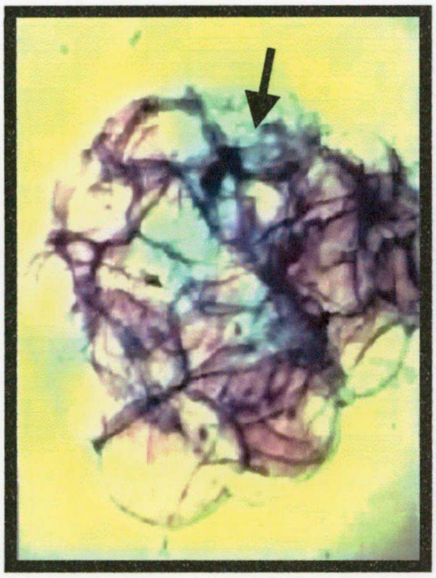

Fig. 24: Group of adipocites during supravital *Trypan-blue* staining. Most of the cells are not stained proving their viability (arrow shows a *stained* dead cell).

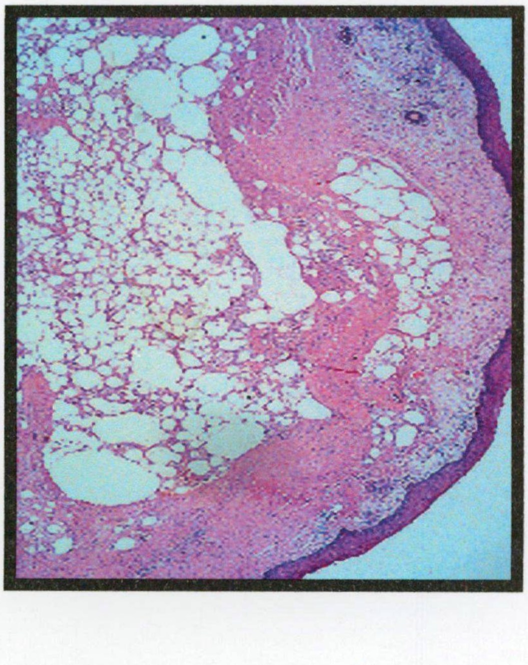

Fig. 25: Hematoxylin-eosin stained vocal cord three weeks after the lipo-augmentation procedure (original magnification: 70x). The transplanted fat tissue can be seen in the TAM (see details in the text).

Patient's ratings: Fourteen patients were asked to complete a short questionnaire ratings in three aspects of postoperative improvement of their voice in the first and in the sixth postoperative month using a 5-point scale with 1=poor and 5= excellent. These aspects were the improvement of range, the dynamic and the roughness of their voice during the normal daily activities.

The pre and postoperative change of *fundamental frequency (FF)* and *maximum phonation time (MPT)* of sustained "i" were examined in 14 patients, and the *maximum voice intensity (MVI)* was measured in five patients as an objective parameter preoperatively and in the third postoperative month by *Storz laryngostrobe* laryngostroboscope. The values were evaluated statistically by paired t-test.

II. 3.3. *Results*

Videolaryngostroboscopy: There were no surgical complications, including granuloma formation. Generally the true vocal cords were somewhat edematic, but did not appea inflamed. The "overfilling of the cords, through the midline a little bit, causes some closure insufficiency in the first one to three postoperative month, with some rigidity of the vocal cords. In 13 patients this bulging disappeared later and perfect glottal closure could be detected, usually including the posterior commissure too (Fig. 21. b; 23.). The positioning of the vocal process remained unsatisfactory in one patient with an almost lateral preoperatively position, but the bowing could be corrected well. In two cases the good result was only temporary and a significant postoperative decrease of glottal closure was detected later, which necessitated reoperation. In one of these cases the result was satisfactory, but in the other one a worsening presented again. 2 months later this patient was later lost from follow-up. The mucosal waves gradually improved during the first three months, and they were close to normal compared to the healthy side.

Histological examinations: The loss of *Trypan blue* staining proved the viability of a large number of adypocites in all of the examined tissue samples (Fig. 24.). Examination of the laryngectomy specimen showed the presence of the fat graft bolus in the vocal cord. Under magnification the fat graft had almost normal architecture (Fig. 25.) with some in-growing blood vessel in the peripheral area, but some lipid filled cystic cavity could be detected similarly to the histological pictures of lipophag granuloma.

Magnetic resonance imaging (MRI): A light area in the mass of the filled vocal cords represented the transplanted fat in all T1-weighted images in the examined four cases (Fig. 22.; 23.).

Phoniatrical examinations

MVI: significant improvement was detected in all five cases (Table V)

Table V. Change of the MVI after the vocal cord lipo-augmentation procedure

Intensity (db)	Patients				
	1	2	3	4	5
preop.	65	60	<50	72	<50
3rd month	97	105	87	95	82

The *MPT* significantly improved after surgery. The preoperatively measured average 7.3 sec. (SD=3.7 sec.) increased to 16,7 sec. (SD=5.7sec.) in the third postoperative month, which is above the lower limit of the normally measured 15 sec. maximum phonation time in human (112). The *FF* decreased after surgery. The preoperatively measured average 246 Hz (SD=54 Hz.) decreased to 201 Hz (SD=49.7sec.) in the third postoperative month. The differences was statistically significant at p=0.05.

Patient's ratings (Table VI): Improvement of voice parameter was not so favorable in the first postoperative month, but significant improvement was found later in the 6th postoperative month compared to the first postoperative month at p=0.05 by unpaired t-test.

Table VI. Patients' ratings

n=14	1st month		6th month	
	avg.	SD	avg.	SD
roughness	3.14	1.03	4.29	1.27
speech dynamic	2.21	0.89	3.43	1.28
voice range	2.29	0.83	3.29	1.20

avg: average; SD: standard deviation

II. 3.4. *Discussion*

Although, *Brünings* published the vocal cord augmentation with paraffin for the treatment of dysphonia in 1911 (144) the surgical technique has not changed significantly so far. Improvement can be observed rather in the implanted materials than in surgical technique. Various types of alloplastic materials have been applied for this procedure so far like bovine bone dust, Tantal powder, silicon powder, bovin collagen or the most widely accepted Teflon (tetrafluoroethylen). All of these materials have a potential problem with hypersensitivity reaction, consecutive vocal cord stiffness, foreign body reaction or migration etc. (112). *Arnold* (145), in 1957, introduced first the autogenous cartilage from the nasal septum in order to avoid these side effects but the cartilage paste has not become popular because of the difficulty in harvesting, dicing, and sterilizing. *Dedo and Row* (157), in 1983, published vocal cord lipoaugmentation via laryngo-fissure, but the first report about the endoscopic procedure was published in 1991 (146).

The surgical technique described by *Brünings* (144) is based on his special "laryngeal syringe", which has been routinely used over the decades for the injection in patients with unilateral VCI. Surgery is generally performed by indirect laryngoscopy in local anesthesia in order to monitor the voice. Nevertheless, this approach has many disadvantages. The correct insertion of the laryngeal needle is difficult even in the hand of the well-trained surgeon in an excited patient (158), especially when multiple injections must be applied. On the other hand, to prevent the patient from surgical stress by general anesthesia is a basic expectation in modern surgery. For this reason some authors suggested intratracheal narcosis with thin tube. According to our opinion this technique has two significant drawbacks. Intraoperative monitoring of the voice is lost. The tube causes a mechanical blockage during augmentation, thus the vocal process cannot be pushed well into the midline. The injected high consistency fluid-like material will rather spread anteriorly into the membranous part of the vocal cord. This must be the main reason for the postoperative closure insufficiency in the posterior glottic chink (146), and this is why authors usually suggest this procedure only for the paramedian vocal cord position with small closure insufficiency (159).

In 1998 we reported our modifications of the endoscopic augmentation procedure to solve the above mentioned problems (XV, XIX). We suggested the controlled myorelaxation narcosis for the intraoperative monitoring of glottal closure. The idea is based on the intraoperatively evoked reflex similarly to the stapedius reflex control during cochlear implantation (160). When the myorelaxation level measured with the TOF- guard system is less then 20 % the protective laryngeal reflex can usually be evoked by mechanical irritation of the glottic mucosa. Thus, glottic closure can be evaluated, and can be further corrected even during surgery, *if supraglottic JET- ventilation is used.* The use of a bivalve laryngoscope combined with JET-ventilation for the approach of the glottis provides maximal mobility for the cricoarytenoid joint and thus less resistance during the medialization procedure. These modifications provided good postoperative glottal closure and voice even in case of atrophised vocal cord, in intermedier position with large glottal gap in our series.*Neuber* (cit.: 159) first described using autologous fat to correct variouse types of defects in 1983. He reported failure when large tissue blocks were employed but success with smaller samples. *Peer* (161) proved with a study of fat transplantation that small-volume free fat grafts can survive by osmotically obtaining a nutritient supply until vascular supply is established (cell survival theory). *Hudson et al.* (162) attempted to determine the best side for fat graft harvest based on assumption that largest cell size and increased lipogenic enzyme adipose tissue lipoprotein lipase (ATLPL) activity would increase viability. They found that the trochanteric region had a greater average lipocyte diameter and increased ATLPL activity. This region has proved also a good harvest field in our practice (IX). However, the harvesting technique may have an influence on the long-term efficacy of the procedure. *Nguyen et al.* (163) claim that up to 90% of the adipocytes are disrupted under standard negative pressure of 1 atm. *Kononas et al* (164) also demonstrated via animal experience that surgically excised fat maintained greater volume than suction-aspirated fat grafts. Histologic evaluation 9 months after transplantation revealed greater cystic degeneration, lipid cavities and fibrosis if transplants harvested by aspiration. Our examination by *Tripan-blue* supravital staining also demonstrated the high number of viable adipocytes in the prepared fat tissue which is the base factor of long-term results (IX, XIX). According to our opinion as minimal mechanical trauma is necessary as possible during fat preparation, hence, after a gentle fat preparation and dicing the fat tissue, it must be injected by the widest laryngeal needle as soon as possible into the vocal cord (VII, XV). The beneficial effect of washing the transplant material in saline or soaking it with human insulin (159) is more theoretical than practical according to our results. The laryngectomy specimen also proved the efficacy of our simple harvesting technique with the presence of the organized masses of normal-appearing transplanted fat tissue with ingrowing vessels and with only mild degeneration signs. *Bauer et al.* (165) and *Shaw et al.* (159) also described the histological evidence of transplanted fat survival in the human vocal cord in the 5th and 18th postoperative month. In accordance with *Brandenburg*'s findings (166), our MRI results also proved the presence of viable fat in the vocal cord even several months after the procedure (IX). In our study approximately 20%-30% of spontaneous fat absorption can be considered usually. If the vocal cords were "overfilled" by this percent, the bulging usually disappeared after three months. Absorption stopped after this period as laryngoscopic images proved this. Following absorption, the vocal cord positions remained stable in 14 cases.

Theoretically we can conclude that the larger amount of transplanted fat tissue is used the relatively higher percentage of absorption can be expected, because revascularization of the central area would take more time. This problem could appear mostly in the case of intermedier vocal cord position or in the case of a "large" man larynx. A repeated surgical intervention can be the suggested solution in these patients. Nevertheless, other, probably individual factors can play role in the long-term success of augmentation as one of our patient's two unsuccessful lipo-augmentation procedures proved.

The patients' ratings well correlate with the laryngoscopic findings. They felt usually only moderate voice improvement in the first postoperative month, but the rating increased gradually until the end of the third month, especially from the point of view from roughness. The increase of MPT and MPI are unequivocal objective evidence of voice improvement. The increased FF can be explained by the contraction of the contralateral vocal cord during forced phonation if the paralyzed vocal cord is not in the midline. Thus, the significant decrease of this value is also an indicator of better phonation after the augmentation procedure (112,159).

CONCLUSIONS AND NEW RESULTS

1. *Study of Ansa Galeni* (I, II, XIV)

The complex sensorial and motoric control of the larynx is supplied by the SLN and the RLN. Our anatomical dissections support opinions, that these nerves do not work separately, but they form a complex neural network, with some overlap of each others function. The AG is a constant connecting area between the two major laryngeal nerves. The fibers originate from the well-defined lower branch of the internal part of SLN before the crossing of the hyothyroid membrane and reach the RLN in the level of the cricoid cartilage.

Our neuromyographical study could not confirm direct motoric innervation of the intrinsic laryngeal muscles through this anastomosis. These axons probably take part in the innervation of the submucosus and upper tracheal sensory receptors. The electric stimulation of AG causes the closure of the glottis, thus this sensitivity may be used for reflexes that protect the lower airways and the lungs. Even a momentary loss of this "protective laryngeal reflex" is rapidly followed by life-threatening pneumonia, thus over the theoretical interest this fact has gained an important role from the surgical anatomical view of our clinical practice of laryngeal cancer treatment. During supraglottic laryngectomy, the main barrier of the larynx: the epiglottis, the aryepiglottic folds, the ventricular folds, in extended surgery cases the base of the tongue or one of the arytenoid regions are removed. This not only means voluminous loss of tissue, but also the loss of mucosa, which contains the mechanical and pressure receptors of this area. This may lead to more or less severe insufficiency in the complex reflex mechanism of swallowing with a risk of aspiration. Our results confirmed *Czigner's* clinical observation about the importance of preservation of the descending part of the internal branch of SLN during supraglottic resection on an experimental base (167). The upper part of the SLN is well identifiable during surgery in most cases, so the afferent arch of the subglottic and upper tracheal protective reflex can be preserved. Moreover the AG innervated part of the piriform fossa mucosa used for the reconstruction of the new laryngeal entrance can also be an additive factor to diminish the volume and duration of postoperative aspiration. These factors can explain that life threatening aspirations in *Czigner's* series of supraglottic laryngectomies necessitate the removal of the rest-larynx only in a very small percentage of cases (168).

2. *Movement of the cricoarytenoid joint* (XIII).

Although, the exact mechanism of this movement in the cricoarytenoid joint can be debated, our result supports the opinion, that the dominant mechanism of abduction in an "average" cricoarytenoid joint is rocking sidewise, outward and upward, and vice versa in adduction. Thus the arytenoid cartilage with the vocal process moves *in three dimensions, not in a plane as the classic rotation mechanism suggests*. This theory, raises many other questions about this regional physiology of the larynx. One of the most important is: how can the internal laryngeal muscle activity and the effect of the capsular ligaments be fitted in the generally presumed mechanism. The examination of this question would gain practical meaning in the future.

Understanding of the *three dimensional movement* of the cricoarytenoid joint has essential importance for the performance of vocal cord "more physiological" surgical medialization and lateralization. Our clinical experiences show that appropriate selection of the surgical approach and the way of ventilation may basically determine the efficacy of the surgical intervention. It is evident, that the mobility of the arytenoid cartilage during operation is essential for long-term good results. For example, the intratracheal tube in the posterior commissure directly, and the tube pushed into the anterior commissure by laryngoscope, causing the tension of the vocal ligament, indirectly decreases the mobility of the arytenoid cartilage and thus its movement into the required position. Hence, the application of a supraglottic JET-ventilation instead of intratracheal tube during operations on non-tracheotomized patients is also an unambiguous fact during operations. The improved efficacy of these modified endoscopic managements of cricoarytenoid joint motion disturbances are detailed in the clinical part of this thesis.

3. *"Early" vocal cord laterofixation* (III, IV, VI, X, XII, XVI, XVIII, XX)

The bilateral vocal cord immobility can be reversible in many cases, thus the otolaryngologist should be aware of the treatment in order to optimize the patient's care and avoid unnecessary diagnostic and therapeutic endeavors. In our series, we introduced an alternative treatment option instead of the classic, usually tracheostomy dependent concept in the early phase of paralysis. The modification of *Lichtenberger's* endo-extralaryngeal simple suture lateralization technique can provide an immediate effective stable airway, when the cricoarytenoid joint can be considered to be mobile in the first postoperative year. Shaping the surgical technique to the physiological cricoarytenoid joint abduction mechanism could lead to a more effective procedure, moreover, as tissue resistance of the abducted cricoarytenoid joint is significantly reducible, only one fixing suture is sufficient; the "external" part of the operation can also be minimized and postoperative tracheostomy is generally not necessary. These provide short surgical duration. The prevention of the membranous part of the vocal cord may ensure the development of relatively good postoperative voice.

In case of vocal cord recovery the returning movement is easily recognizable even on the laterofixated side and the fixing suture is easily removable. Significant improvement or spontaneous remedialization with increasing voice quality can be noticed after this within weeks depending on the reinnervation status of the vocal cord.

In our eight-year experience the airway remained generally stable in the long run in case of permanent paralyses, thus this intervention may mean the final solution of the suffocation too.

Finally, we can conclude that the vocal cord recovery can be expected without the need for tracheostomy or severe limitation of quality of life, and the method might provide a one-stage solution of suffocation when vocal cord immobility proves to be permanent. Our therapeutic concept is suggested in accordance with the policy of minimally invasive surgery and is a reliable alternative for the classic treatment approach.

4. Minimally invasive surgery for posterior glottic stenosis (V, VIII, XVII)

As our series also proves, a scarred fixation of the posterior glottic commissure can usually be found generally in the background of postintubation or "post-traumatic" vocal cord immobility. Nowadays, failed interventions made for bilateral vocal cord paralysis form a new group of this entity. Nevertheless, in these cases the paralysis is present, but the more-or-less massive scar formation in this region with generally median vocal cord position means the real problem of treatment.

In this study we have introduced and evaluated a new minimally invasive endoscopic method applied instead of the earlier, tracheostomy dependent, often external surgical procedures. The method recommended is a simple, well-tolerated procedure that gives an immediate adequate airway without the need for tracheotomy. Application of this surgical technique shows that recurrent scarring can be prevented in cases when the cricoarytenoid joints are not involved in the scar (type I, II, and selected cases of type III glottic stenosis according to the *Bogdassarian-Olson* classification). Good functional results were noticed from the point of view of breathing, and appropriate vocal cord recovery and voice could be detected after the removal of the fixing sutures. We found that even the "extended" procedures are only partially sufficient in cases of type IV posterior laryngeal stenosis, when the joints are fixed by the scar, but the result is comparable with the procedures – arytenoidectomy and transverse cordotomy – which can lead to a definitive „rough" injury of the larynx. In these cases and when the stenosis is associated with vocal cord paralysis (postarytenoidectomy cases) the vocal cord recovery cannot be expected, thus the removal of the sutures is not suggested in order to improve long-term results.

5. *Vocal cord lipo-augmentation for the phonosurgery of unilateral vocal cord paralysis.*
(VII, IX, XIX)

The effort to minimize the patients' physical and psychical stress during the surgical intervention necessitates the use of general anesthesia. Nevertheless, this contradicts the expectations of phonosurgical interventions, because the continuous voice control is obligate in these cases, thus these types of surgery are often performed in local anesthesia. Our refinement suggested the myorelaxation controlled augmentation procedure combined with supraglottic jet-ventilation and with *Weerda* bivalve laryngoscope approach. According to our opinion this combination provides the best mobilization of the cricoarytenoid joint, thus the placing of the operated vocal cord with the vocal process to the midline even in case of large glottal gap. Moreover, it provides intraoperatively controllable good glottal closure in spite of the general anesthesia and it may prevent the technical failures of misplacement of the injected material. Our results suggest, that our modification of vocal cord augmentation technique is applicable even in case of a unilateral vocal cord immobility with large glottal gap. We suggest the use of this method in any case of filling material especially in case of Teflon- or other nonabsorbable filling substances when precise closure control is perhaps more important.

Our study confirmed on a histological basis and on clinical and on phoniatrical investigations the long-term efficacy of the lipo-augmentation procedure in most cases even in case of a large glottal gap. In our series the fat tissue proved to be readily available, cheap, easily harvestable and injectable material without the risk of foreign body or hypersensitivity reaction. There is no risk of extrusion of the implant. It provides good phonation with good long-term results for years in our practice.

Failures present usually in absorption of the fat. According to our results the use of appropriate harvesting technique (liposuction is not preferable) and the appropriate timing of the procedure waiting for the maximal atrophy of the TAm (8-12 months after the onset of paralysis) and the 20-30% "overfilling" can avoid this problem. The procedure is minimally invasive, thus it can be applied repeatedly.

Considering the above mentioned advantages of the autologous fat and our modification of the augmentation technique we suggest it as the one of the "most physiological" primary treatment of unilateral vocal cord paralysis.

LIST OF THE AUTHOR'S MAIN SCIENTIFIC PUBLICATION

(related to the subject of the thesis)

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ABBREVIATIONS

AG: ansa Galeni (Galen's anastomosis)
CAJ: cricoarytenoid joint
CTM: cricothyroid muscle
FF: fundamental frequency
IAM: interarytenoid muscles
LCAM: lateral cricoarytenoid muscle
LMG: laryngomyography
MPT: maximum phonation time
MVI: maximum voice intensity
MRI: magnetic resonance imaging
NG: nodal ganglion
PCAM: posterior cricoarytenoid muscle
RLN: recurrent laryngeal nerve
SLE systemic lupus erythematosus
SLN: superior laryngeal nerve
TAM: thyroarytenoid muscle
TOF: train of four
VCI: vocal cord immobility

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