SURGICAL-ANATOMICAL ASPECT OF THE CRICOARYTENOID JOINT

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Summary of Ph. D. Thesis

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1. INTRODUCTION AND AIMS OF THE THESIS

The main structural elements and the function of the larynx were recognized in times of antiquity, nevertheless, the fine anatomical details 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. Since 1986 the laryngeal disorders have became the mean research field of our clinic. The surgical aspects of the laryngeal anatomy, the cricoaritenoid joint (CAJ), the sensorial and motoric innervation of the larynx have become a targeted problem through decades in the function preservation endo- and open laryngeal cancer surgery. I have been involved in the research team of Professor ***Jenő Czigner*** and Professor ***József Jóri*** since 1990. My task was to study these questions from the point of view of the non-malignant laryngeal diseases, especially in the patophysiology and treatment of the motional disorders and glottic stenosis of the larynx.

The development of new diagnostic tools and the new surgical instruments 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. 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.

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.

1.1. **Surgical-anatomical and neuromyographical study of ansa Galeni (AG)**

Throughout the history of laryngology, investigations have studied and compiled theories about the vocal cord in cases of paralysis, the physiologic basis for fold position and functional deficit, and the prognosis or likelihood of recovery. Many theorems have been raised in the last centuries to explain this, from the first suggested theory of *"posticus paralysis"* (*Semon-Rosenbach law*, 1881) to the nowadays widely popular *idea of synkinetic activity*. The contingent role of the superior laryngeal nerve in the innervation of the intrinsic laryngeal muscle, beside the well-known external branch, is a returning theory in the history of laryngology (*Ónodi*, 1902). One of these was *Réthi's parallel innervation theory*. He described in 1955, 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 through an anastomosis to the recurrent laryngeal nerve the superior laryngeal nerve controls this activity. In our study, in 1992, based on dog larynx and human intraoperative anatomical investigations we tried to confirm this theory on an experimental basis.

1.2.. **Analysis of the cricoarytenoid joint movement by picture digitalization technique**

The exact anatomy and workings of the CAJ was a matter of debate even at the end of the 20th Century. Present theories suppose the separate or combined presence of three main forms of movement: rotation around the axis (*Neuman et al*, 1994) 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 (*Fink*, 1975; *Tucker*, 1987) additionally a rotation around the axis in the plane of the joint surface (*Wang*, 1998; *Selbie*, 1998) thus rocking forward or backward. These - more or less contradictory - theories are generally based on the top-view picture of 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 because the hidden position and the soft tissues covering the joint do not allow direct examination. In our other theoretical study we analyzed this debated mechanism. *The CAJ 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 the theoretical field in literature. It is obvious, that perfect understanding of its mechanisms is basically required in the search of accurate, new and

more physiological treatment modalities for the treatment of glottic motional disorders. 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 and cricoarytenoid joint immobility (VCI).

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

Glottic stenoses are a well-defined part of laryngeal disorders. Nowadays the paralytic disorders of the vocal cords and the CAJ 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 is reported recently 0.5- 3.2%, but in case of reoperation or malignancy this ratio may increase up to 10%. The bilateral recurrent nerve injury causing acute respiratory failure is fortunately rare, less than 1%.

Endoscopic arytenoidectomy with or without cordectomy (*Kleinsasser*, 1968; *Lichtenberger and Toohill, 1998* etc) became the most accepted intervention for the permanent bilateral vocal cord paralysis at the end of the 20th Century, and practically replaced the external surgical methods. Nevertheless, these interventions can be applied only in limited conditions in the first year of the paralysis, when it is potentially reversible. 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 view of laryngeal functions.* In the routine clinical practice only tracheotomy was suitable for this requirements until the end of the last century, *because all the surgical procedure dissolving the unit of the CAJ and the vocal cord causes irreversible damage in the larynx*. For the accomplishment of this dilemma many authors suggested minimizing the resection of arytenoidectomy (*Crumley*, 1993) and/or cordectomy (*Dennis and Kashima*, 1989) for an acute applicability; or to determine paralysis reversibility by laryngomyography (*Thumfart,* 1988), but the practicability of these is a debated question even nowadays (*Woodson*, 1998 etc). Therefore, the conventional, "golden standard" surgical treatment strategy has not changed in case of severe suffocation: *the first step is tracheotomy to save the patient from choking, and minimum six months later a common definitive surgical intervention to open up the paralyzed glottis* (*Krepuska,* 1942).

The main steps of resolving of the *immediate minimally invasive treatment* of this type of stenosis was *Lichtenberger's endo-extralaryngeal* vocal cord lateralization technique (1982) and *Ejnell's and Tisell's* idea of a new treatment concept: the "acute", "reversible" *exo-endolaryngeal* vocal cord lateralization *immediately* after bilateral recurrent nerve injury (1993). In 1995 we introduced a new treatment concept for the acute, minimally invasive solution of dyspnea *to avoid tracheotomy,* adapting a modified *endo-extralaryngeal* suture vocal cord lateralization technique for the idea of "reversible vocal cord laterofixation". *The modification mainly turned attention to the unit of the CAJ and vocal cord in order to optimize the surgery for the concept of "early" vocal cord laterofixation.*

1.4 Minimally invasive surgery for posterior glottic stenosis (PGS)

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 can occur 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, etc. The number of intensive care patients significantly increases in Hungary too. While this number was approximately 48 000 in 1998, as far as in 2001 it was already more than 65 000 according to the data of the Hungarian Health Care Insurance. These medical interventions may lead to hundreds of bilateral vocal cord disorders in every year. Nowadays PGS has been associated with other iatrogen factors, mostly surgical interventions in the posterior glottic area, such as treatment of recurrent papillomatosis or failed treatment of bilateral VCI etc.

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

Many different endolaryngeal or extralaryngeal procedures have been devised for the PGS. The common concept of all these surgical interventions is the transsection or removal of the scar tissue and somehow detain the development of the restenosis by stenting (*Lichtenberger*, 1992), mucosal flap (*Dedo and Sooy*, 1984), or posterior laminotomy (*Réthi*, 1955) etc. The disadvantage that 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.

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

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 the voice. 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 the 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 fields of laryngology in the last decades.

The phonosurgical procedures can be divided into three groups. In spite of the good experimental results, the theoretically superior *reinnervation procedures* have not gained wide acceptance in the clinical practice The vocal cord was placed medially by some type of alloplastic material (first by Paraffin, later by Teflon, Gore-tex, Silicone, Titanium etc). in the course of *endolaryngeal vocal cord augmentation* and *external laryngeal framework or thyreoplastic surgeries*. Nevertheless, these materials have some risk of foreign body reaction, extrusion etc, and they can cause functional problems by the stiffness of the vocal cord.

The original surgical technique of the vocal cord augmentation described by *Brünings* in 1911 is based on a 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, 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 and this minimally invasive, theoretically simple procedure was usually suggested only for the paramedian vocal cord position with small closure insufficiency.

The aim of the thesis

1: *a*: Justification of the presence and clarification of the surgical-anatomical details of an invariant intralaryngeal anastomosis between the superior and recurrent laryngeal nerves, by animal and human anatomical dissections. *b*: Examination of the possible role of this anastomosis in the patophysiology of the laryngeal motion disorders and: to clarify the role of its sensorial fibers to draw attention to the possible clinical importance of AG.

2: Determine the CAJ movement from surgical-anatomical point of view by our movement averaging technique on large number of cases and adding the results to the findings of modern anatomical examinations to define what the most realistic movement of the CAJ is.

3: Working out a new minimally invasive, clinically effective and suitable treatment concept for the acute bilateral vocal cord and cricoarytenoid joint immobility what provides an immediate *physiological abducted arytenoid and vocal cord position* thus an adequate airway and the

reversibility from the point of view of laryngeal function. Evaluation of the long-term efficacy of the surgical technique in case of permanent bilateral VCI.

4: Elaboration of a new minimally invasive, potentially reversible surgical technique based on the surgical-anatomical aspect of CAJ for different kind of etiology and degree of PGS what can replace the earlier, generally tracheostoma dependent surgical techniques.

5: *a*: Functional and histological evaluation of the vocal cord autologous fat augmentation for unilateral VCI and introducing it to the Hungarian clinical practice. *b*: Modification of the original surgical technique: 1: in order to provide a more physiological adduction for the *unit of CAJ and the vocal cord.*; 2: to achieve the intraoperative control of the appropriate glottis closure even in case of the nowadays required general anesthesia

2.1 Surgical-anatomical and neuromyographical study of ansa Galeni

The animal examinations were performed on canine larynx (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. 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 in the literature. 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 thyroarytenoid muscle (TAM) as one of the adductor muscles of the larynx and into the abductor posterior cricoarytenoid muscle (PCAM). The examined nerve was stimulated by a single, rectangular stimulus with 1 V voltage, and 200 msec. stimulating range. 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. 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 noninfiltrated side of the larynx.

2.2. Analysis of the cricoarytenoid joint movement by picture digitalization technique (XIII)

During the examination we analyzed the movement of the larynx of voluntary 50 men and 50 women (between 17 and 67 years), all with a healthy larynx. After applying local anesthetics to the pharynx and the larynx with 10% and 2 % Lidocain, we introduced the 70º Storz rigid endoscope and recorded the picture of the larynx on S-VHS video cassette, in the changing phases of minimum 3 quiet sounds "i" (adduction) and deep breathing (abduction). 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. Four points were marked on the pictures of adduction and abduction on the right side: anterior commissure (A); the posterior edge of cricoid cartilage (B), corniculate cartilage (C) representing the apex of the arythenoid cartilage; vocal process (D). 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. The endoscopic techniques can show the top view projection change in the proportion and direction compared to the AB section considered permanent. Because of 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 normalization technique used in vectorial algebra. Relative values for movement measured in the above mentioned way were magnified to make all AB sections 10 cm (for better visual understanding), this way the proportional movement of arytenoid cartilages became comparable and statistically processed. The changes in the projection of the arytenoid cartilage were examined by an unpaired t-test, and the difference between sexes by a paired t-test.

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

Forty-two consecutive patients (33 women and 9 men) were operated within six months from the detection of bilateral VCI from August 1995 to August 2002. The time between the onset of paralysis and the laterofixation procedure ranged from 1-122 days (mean: 17 days).

We used a modification of *Lichtenberger's* Type-A endo-extralaryngeal suture technique for the vocal cord lateralization.. The procedure is performed under general anesthesia. 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.* In most of our patients a *Weerda*

laryngoscope combined with supraglottic *low-frequency Jet ventilation* was used to open up the glottic space, and trans-stomal intubation was carried out in some patients with tracheostomy arrived to our clinic with canula. 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. First, the cricoarytenoid joint mobility is examined by passive mobilization 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 Lichtenberger's needle carrier instrument. Then a monofilament, non-resorbable thread (#2-0, or later always 0 Prolene) is passed under the vocal process out to the surface of the neck. This action process is repeated with the other end of the thread above the vocal process by pushing the arytenoid cartilage slightly backward again. The thread forms a loop around the vocal process then, permitting the creation of an almost physiological abducted CAJ position.* 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 (X, XII). *The external surgeon makes an approximately 5-10-mm-long incision between the two ends of the thread, pulls back both ends under the skin with a Jansen-hook, and ties a knot above the prelaryngeal muscles* (III, IV, VI, XVI). *This procedure generally does not require tracheostomy defense.*

The reversibility of this concept means that the lateralized vocal cord, depending on its reinnervation status, 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 (XVI).

2.4 Minimally invasive surgery for posterior glottic stenosis

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. There were one type I, four type II, two type III and seven type IV stenoses according to *Bogdasarian and Olson*.

The procedure is performed with the patient under general anesthesia, and a Rüsch tube is introduced for intubation or Jet ventilation anesthesia. Earlier a *Kleinsasser*, nowdays a *Weerda* laryngoscope is used to expose the posterior glottic space. The scar is excised by CO_2 laser, without touching the postcricoid mucosa. The mobility of the cricoarytenoid joint is examined with passive mobilization, and the classification of the stenosis is established. In case of a fixed joint, the arytenoid cartilage is moved with a *Magill* forceps, following the direction of the joint's physiologic movement. In the cases of severe stenosis, when reoperation was necessary a more extensive scar mobilization was performed with the opening of the cricoarytenoid joint via antero-medial aspect by CO2 laser.

The cardinal part of the procedure is the arytenoid laterofixation with the vocal cord similarly to the way described for the "early" vocal cord laterofixation (chapter 2.3). Application of this procedure after the excision of the scar tissue and allow the wound sites to be held apart from each other until the reepithelialization of the posterior glottic area. When reepithelialization 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

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

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 neuroma.

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 on minimum six months after the onset of the paralysis and in these cases the preoperatively applied speech therapy had not provided satisfactory results.

Surgery was performed in total intravenous anesthesia (TIVA) using Propofolol 2 mg/kg in bolus continued 6mg/kg/h by perfusion pump combined with short-term myorelaxant (Norcuron 35 mg/kg) used for controlled myorelaxation (TOF-guard system). Intubation narcosis remained for the fat harvesting procedure, but the endoscopic augmentation procedure was performed by supraglottic low-frequency Jet-ventilation.

The fat tissue was surgically harvested (not by suction) from the left trochanter subcutan area and diced by scissor removing any fibrous tissue. *Weerda* laryngoscope was used to open up the larynx. 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 CAJ 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, and then the second bolus was injected in the medial third of the vocal cord as close as possible to the thyroid ala to correct the contour of the vocal cord. 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.

Postoperative measurements and follow-up:

Videolaryngostroboscopy:

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

Phoniatrical examinations:

Patient's ratings: Fourteen patients were asked to complete a short questionnaire with 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 "í" 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. The values were evaluated statistically by paired t-test.

Magnetic resonance imaging (MRI):

The long-term survival of the fat tissue was demonstrated by T-1 weighted MRI in 4 patients in the first, in the third, in the sixth and in the tenth postoperative month.

Histological examinations:

Trypan blue supravital staning was performed in five patients in order to prove the presence of viable adipocytes in the transplanted material. Trypan blue will stain dead or dying cells. Viable cells are able to repel the dye by pinocytosis and do not stain.

Hematoxylin 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.

3 RESULTS AND DISSECTIONS

3.1 Surgical-anatomical and neuromyographical study of ansa Galeni

3.1.1 Results

Anatomy: The SLN divides into an outer and an inner branch above the level of the hyoid bone. 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 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. 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: W*e could complete 8 neuromyographic examinations on the 5 dogs. 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 we could detect a response from the TAM with the same amplitude and latency as the former had. When the SLN was cut 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.

3.1.2 Discussion

Our results confirmed *Ónodi*'s findings that the AG originates from the inner branch of the SLN, but the exact place of the branching off has not been discussed so far. 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. 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 intramuscular branches and *innervates the ipsilateral crycoarytenoid area*, later it forms an acute-angled connection with the RLN at the lower edge of thyroid cartilage (I, II).

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 and in magnitude with other reflexes that have been described in the literature. Thus, the sensory fibers probably start from the sensorial receptors of the subglottic area and travel in AG and then join the other sensory nerves of SLN and get through the nodal ganglion. Then they synapse with the motoneurons of the dorsal nucleus of the vagal nerve, 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 *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.

3.2 Analysis of the cricoarytenoid joint movement by picture digitalization technique

3.2.1 Results

The projection of the 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 the 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.

I. 2.4. *Discussion*

The classical anatomical studies have explained the structures of CAJ in details. The new investigations focused on explaining the exact mechanism of the joint by CT scan, 3 directional x-ray examinations and by digitalization of MRI of the articulation facets, but only in small number of cases. 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. The fact that the projections of movement are parallel definitely exclude *rotation*, since it assumes an angle of minimum 30 degrees. *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. 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. The axis of ***rocking*** is almost the same as the longitudinal axis of the joint. 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). *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).* Thus, the whole arytenoid cartilage together with the vocal process moves outward during inspiration, making the lumen of the cricoid cartilage totally open.

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

3.3.1 *Results*

Results within the first postoperative years:

Unilateral vocal cord laterofixation provided adequate airway in 39 patients, 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. 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:

Severe vocal cord medialization, when the vocal cord got back in paramedian position, was detected in two cases. Other, not so significant spontaneous medializations were detected in other five cases. A 79-year old and a 75-year old woman was tracheotomized because of repeated pneumonia caused by chronic aspiration in the seventh and the ninth postoperative month.

However, the patients' dysphonia grew significantly worse after surgery, and their voices became hoarser 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 laterofixed 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 and in two cases only the laterofixed 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.

Results of permanent bilateral VCIs:

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 *21 permanent bilateral VCIs could be 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 laterofixating 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 primary "early" vocal cord lateralization has provided the definitive solution for adequate airway in* ***16 of 21*** *patients with permanent bilateral VCI.*

3.3.2 Discussion

In our new therapeutic strategy we introduced the modification of *Lichtenberger's* original "A technique" as an acute, potentially 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. 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 is 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. This kind of arytenoid laterofixation could have been achieved only by the one of the most effective external surgical intervention so far, by the *King-Schobel* technique. 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). Supraglottic JET ventilation provides an excellent evaluation of glottic diameter; thus, it becomes possible during surgery to determine individual glottis width. A mobile arytenoid cartilage can be rotated easily in the early period, an important fact in carrying out the vocal cord laterofixation procedure as soon as possible. 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. The access to the thyroid ala is not needed; therefore, in our experience the *entire operation takes approximately 10-15 minutes.* Considering the proved reversibility, we usually 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).

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). According to the patients, almost complete restoration of preoperative voice was achieved when recovery was bilateral. Most of the patients were usually able to return to their previous lifestyles soon.

3.4 **Minimally invasive surgery for posterior glottic stenosis**

3.4.1 *Results*

All of the patients' glottis became adequately wide right after this surgical procedure, nevertheless, in six cases the intensive antiedematic conservative treatment continued approximately for a week. The preoperative FIV-1 values generally increased more than 100%. 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 was detected, and their voice was similar to the quality of their natural voice

according to the patients, but remained slightly hoarse, as a result of a mild phonation closure insufficiency at the site of the suture. They could soon return to their previous life-style.

In cases, when the PGS associated with bilateral joint fixation (type-IV) the functional results showed more or less significant decrease in the long run. In the first two patients in this group reoperation was 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 scar incision with the antero-medial opening of the joint from antero-medial aspect later. This modification diminished the decrease of breathing values. These patients' voice remained hoarse, but socially acceptable.

3.4.2 *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 this surgery. Nevertheless, the simple excision of the scar tissue is usually insufficient for the reestablishment of glottic function. 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– 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 stenosis) 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 reepithelialization after laser glottic surgery. 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 laterofixation, 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 experiences complete vocal cord recovery in cases of a fixed CAJ cannot be expected. The affected vocal cords remain fixed but more-or-less lateral position. The same results can be expected, if the stenosis developed after failed arytenoidectomy. 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 and transsection of the intracapsular scar improves the efficacy of arytenoid cartilage and the vocal cord laterofixation.

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

3.5.1 *Results*

Videolaryngostroboscopy: There were no surgical complications, including granuloma formation. Generally the true vocal cords were somewhat edematic, but did not appear inflamed. The "overfilling" of the cords, through the midline a little bit, caused 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. 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 a

significant decrease of glottal closure was detected, which necessitated reoperation. In one of these cases the result was satisfactory, but in the other one a worsening presented again. Two 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.
Phoniatrical examinations, patient's ratings (Table I)
MVI: The average improvement was more than 30 dB in five cases. 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. 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 were statistically significant at p=005.

Table I:: the average (avg.) and standard deviations (SD) of 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

Significant improvement was found in the parameters measured in the 6th postoperative month compared to the first postoperative month at p=005 by unpaired t-test.
MRI: A light area in the mass of the filled vocal cords represented the transplanted fat in all images in the examined four cases.
Histological examinations: The loss of *Tripan blue* staining proved the viability of a large number of adipocytes in all of the examined tissue samples. 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 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 lipophage granuloma.

3.5.2 *Discussion*

We introduced first the vocal cord lipo-augmentation into the Hungarian clinical practice in 1996 and we reported our modifications of the surgical technique to solve its technical problems in 1998 (XV, XIX). We suggested the controlled myorelaxation narcosis for the intraoperative monitoring of glottal closure. When the myorelaxation level measured with the TOF (train of four)-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 bowed vocal cord, in intermedier position with large glottal gap in our series.

Animal experience demonstrated that surgically excised fat maintained greater volume than suction-aspirated fat grafts. 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 of the fat tissue, it must be injected by the widest laryngeal needle as soon as possible into the vocal cord (VII, XV).

4 CONCLUSIONS AND NEW RESULTS

4.1 ***Study of the 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 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 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.

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. 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. This can be a factor to 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.

4.2 ***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*. 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 these surgical interventions. The improved efficacy of these modified endoscopic managements of cricoarytenoid joint motion disturbances are detailed in the clinical part of this thesis.

4.3 ***"Early" vocal cord laterofixation*** (I, II, XIV)

In our series, we introduced an alternative treatment option for patient with breathing insufficiency instead of the classic, usually tracheotomy dependent concept in the early phase of bilateral vocal cord immobility. Our 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. 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 preservation of the anatomical structure in the membranous part of the vocal cord may ensure the development of relatively good postoperative voice.

In case of vocal cord recovery significant improvement or spontaneous remedialization with increasing voice quality can be noticed after removal of the fixing suture within weeks depending on the reinnervation status of the vocal cords. The returning movement is easily recognizable even on the laterofixed side, thus laryngomyography is generally not necessary.

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 tracheotomy 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.

4.4. ***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, tracheotomy 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). Good functional results were noticed from the point of view of breathing. 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 and destroyed 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.

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

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 vocal muscle (8-12 months after the onset of paralysis) and the 20-30% "overfilling" can avoid this problem.

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 arytenoid cartilage and 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 VCI with large glottal gap in case of mobile cricoarytenoid joint. We suggest the use of this method in any case of filling material especially in case of Teflon- or other non-absorbable filling substances when precise closure control is perhaps more important. The procedure is minimally invasive, thus it can be applied (if necessary) repeatedly.

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

List of the author's main scientific publication related to the subject of the Ph. D. thesis

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III Jóri J, **Rovó L**, Czigner J: Endolaryngealis laterofixatio a tracheotomia kiváltására kétoldali akut hangszalagbénulásban (Endolaryngeal laterofixation versus tracheostomy for treatment of acute bilateral vocal cord paralyses). Magyar Sebészet 1997. 50, 227-229.

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