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The Pharyngoesophageal Segment in Dysphagia and Tracheosophageal Speech

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The Pharyngoesophageal Segment

in Dysphagia and Tracheoesophageal Speech

Beatriz Arenaz Búa



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DOCTORAL DISSERTATION

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<p>Abstract</p> <p>The pharyngoesophageal segment (PES) is made up of the inferior pharyngeal constrictor, the cricopharyngeus muscle and the proximal part of the cervical oesophagus. This location explains why the PES plays an essential role not only in swallowing, but also in voice production after total laryngectomy.</p> <p>In paper I, the Sydney Swallow Questionnaire (SSQ) was translated and validated to Swedish conditions. The Swedish version of the SSQ was tested on healthy controls and patients with oropharyngeal dysphagia and it was found to comply with the criteria for content, construct, discriminant and predictive validity and test-retest reliability. In paper II, we evaluated the treatment of cricopharyngeal dysfunction (laser myotomy versus balloon dilatation) using the SSQ and videomanometry pre- and post-operatively. The treatment improved the PES opening for at least 6 months. We assessed the PES in tracheoesophageal (TE) speakers (functional speakers in paper III, non-functional speakers in paper IV) using high resolution videomanometry, high speed camera recording and voice perceptual assessment. We proposed a phonation index, defined as the ratio between the phonation pressure at the PES and that at the distal oesophagus. Non-functional TE speakers presented both higher phonation pressure at the PES and phonation index than functional TE good speakers. This pressure decreased after treatment with balloon dilatation and/or botulinum toxin. Decreasing phonation pressure from the distal oesophagus to the pharynx was found in functional speakers (who did not require treatment) and non-functional speakers after treatment. In paper V, the SSQ and the Voice Handicap Index-Throat were used to evaluate swallowing and voice problems after total laryngectomy. Swallowing problems were reported by 89 % and moderate/severe voice handicap was reported by 66% of the patients.</p>		
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Beatriz Arenaz Búa

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To my children, Daniel and Lucas

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List of papers

This thesis is based on the following papers, which are referred to in the text by roman numerals I-V:

- I. Arenaz Bua B, Bulow M: Validation in Swedish of the Sydney Swallow Questionnaire. *BMC Research Notes* 2014, 7: 742. DOI: 10.1186/1756-0500-7-742.
- II. Arenaz Bua B, Olsson R, Westin U, Rydell R, Ekberg O: Treatment of Cricopharyngeal Dysfunction: A comparative pilot study. *BMC Research Notes* 2015, 8: 301. DOI 10.1186/s13104-015-1266-x.
- III. Arenaz Bua B, Olsson R, Westin U, Rydell R: The pharyngoesophageal segment after total laryngectomy. *Annals of Otology, Rhinology & Laryngology*. 2017 Feb ;126(2):138-145. doi:10.1177/0003489416681321. Epub 2016 Dec 8.
- IV. Arenaz Bua B, Olsson R, Westin U, Rydell R: The pharyngoesophageal segment in laryngectomees with non-functional voice: Is it all about spasm? *Journal of Otol Rhinol* 2016, 5:4. doi:10.4172/2324-8785.1000287.
- V. Arenaz Bua B, Pendleton H, Westin U, Rydell R: Voice and swallowing after total laryngectomy. Submitted.

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Abbreviations:

BD: Balloon dilatation

BT: Botulinum toxin

CPD: Cricopharyngeal dysfunction

CPM: Cricopharyngeal muscle

DOSS: Dysphagia Outcome and Severity Scale

HRM: High-resolution manometry

HRVM: High-resolution videomanometry

HSC: High-speed camera

ICC: Intraclass correlation coefficient

LM: Laser myotomy

mmHg: Millimetres of mercury

MDADI: MD Anderson Dysphagia Inventory

PES: Pharyngoesophageal segment

Q: Question

r_s : Spearman correlation test

SLP: Speech and language pathologist

SECEL: Self Evaluation of Communication Experiences after Laryngeal cancer

SSQ: Sydney Swallow Questionnaire

Swal-QOL: Swallowing Quality of Life Questionnaire

TL: Total laryngectomy

TE: Tracheoesophageal

TEP: Tracheoesophageal voice prosthesis

UES: Upper oesophagus sphincter

VM: Videomanometry

VHI: Voice Handicap Index

VHI-T: Voice Handicap Index-Throat

Aims of the study

The aim of this thesis was to study the role of the pharyngoesophageal segment in oropharyngeal dysphagia and in voice production after total laryngectomy.

The specific purposes of the studies were to:

Study 1: translate the Sydney Swallow Questionnaire (SSQ) to Swedish conditions. Evaluate the validity and test-retest reliability of the Swedish translation for patients with oropharyngeal dysphagia and for healthy controls.

Study 2: assess the effects of balloon dilatation and laser myotomy in cricopharyngeal dysfunction, using videomanometry and SSQ before and after treatment.

Study 3: use voice perceptual assessment, high-speed camera recording and high-resolution videomanometry to characterise the pharyngoesophageal segment of functional TE speakers and to establish a baseline for normal TE function.

Study 4: use voice perceptual assessment, high-speed camera recording and high-resolution videomanometry to characterise the pharyngoesophageal segment of non-functional TE speakers and assess the effects of treatment with botulinum toxin and/ or balloon dilatation.

Study 5: determine the occurrence of swallowing and voice problems in patients who have been laryngectomized in the South of Sweden between 2000 and 2016, using the SSQ and Voice Handicap Index-Throat (VHI-T).

Introduction

The pharyngoesophageal segment (PES) plays an essential role in the pathophysiology of swallowing disorders. In addition, it is essential for voice production after total laryngectomy. The PES consists of the distal part of the inferior pharyngeal constrictor, the cricopharyngeus muscle and the most proximal cervical oesophagus. The upper oesophageal sphincter (UES) is a 2.5 to 4.5 cm, high-pressure zone between the pharynx and oesophagus. PES refers to the anatomy and UES to the function. Neoglottis is a term used to describe the anatomic segment between the hypopharynx and the oesophagus, which, when vibrating sufficiently, should be capable of producing alaryngeal voice after laryngectomy. In other words, neoglottis describes the PES in laryngectomees.

Problems with the PES are challenging and may require a multidisciplinary team, which should have the ability not only to diagnose and treat these patients, but also to recognise that the effects of swallowing problems extend well beyond mealtime. The rehabilitation of the physical and psychosocial side effects of total laryngectomy should not only prolong life, but also improve the quality of life.

In this thesis, we have used videomanometry and high speed camera examination to evaluate the anatomy and function of the PES. The SSQ and the VHI-T capture the patients' perception of their swallowing and voice problems, and perceptual voice assessment guides the rehabilitation after total laryngectomy.

Swallowing

A normal swallow is the sequential, coordinated and rapid transportation of a bolus from the oral cavity, through the pharynx and oesophagus, into the stomach. A healthy individual, swallows approximately 600 times per day, 50 times during sleep, 350 times when awake and 200 times at meals. Several paired, striated muscles in the mouth and pharynx are involved in swallowing (1). The oesophagus consists of intrinsic circular muscle fibres and longitudinal extrinsic fibres. The proximal one third of the oesophagus consists of striated musculature, the middle third has striated and smooth musculature and the distal third consist of smooth musculature (2, 3). The swallowing process can be divided into three stages: oral, pharyngeal and oesophageal.

Sensory input contributes to these phases. Receptors are present in the mouth, pharynx and larynx to provide the central nervous system with the ability to perceive touch, texture, pressure, shape, temperature and taste. This afferent information is sent to the nucleus of the solitary tract in the brainstem, through the V, VII, IX and X cranial nerves. Close to the nucleus of the solitary tract there is an afferent swallowing centre that interprets the information. If it is found appropriate for swallowing, information goes to an efferent swallowing centre close to the ambiguous nucleus(1). Information also goes to a dorsal swallowing centre close to the posterior nucleus of the vagal nerve. The efferent innervation is through the V, VII, IX, X and XII nerves. The swallowing centre also receives information from several cortical and subcortical regions. However, the pharyngeal and oesophageal swallowing can be evoked also in the absence of these areas, which indicates that the brainstem is the primary swallowing area. Swallowing and respiration neurons are located in close proximity in the brainstem, both functions are temporally coordinated during feeding to avoid aspiration. There is a swallowing apnoea during the pharyngeal phase of swallowing and most swallows are preceded and followed by expiration(4-6). The oral stage of swallowing is completely voluntary, whereas the pharyngeal stage of swallowing is automatic. This automatism means that once the pharyngeal swallow has been elicited, it is always completed and cannot be interrupted(1, 4). The oral stage of swallowing includes ingestion, blending, mixing, and mincing of ingested material. The tongue scoops up a suitable amount of ingested material or “bolus,” which is propelled by a sweeping movement of the tongue into the pharynx. The pharyngeal stage includes the sealing off of the nasopharynx with the soft palate opposing the posterior pharyngeal wall and the closing of the airways by the elevation and closure of the larynx and by the tilting of the epiglottis, which combined with a centrally controlled swallowing apnoea, prevents aspiration during swallowing (5). The pharynx and larynx elevate and the pharyngeal constrictors achieve a final rinsing of the pharynx. The pharyngo-oesophageal segment opens and when the bolus reaches the upper part of the oesophagus, the bolus is propelled downwards by a combination of gravity and contraction in the circular musculature. When this occurs, in connection to pharyngeal swallowing, it is called primary peristalsis. If it occurs by local distension, for instance, by retained material or regurgitated/reflux material, it is called secondary peristalsis (4).

Dysphagia

Dysphagia is the subjective awareness of swallowing difficulties. Swallowing problems may occur in all age groups, resulting for example from congenital abnormalities, structural damage after surgery and chemoradiotherapy, and/or medical conditions. Elderly people require more reaction time to process complex

movements and the number of muscle motor units and fast-twitch fibres decreases with age (7). Therefore, dysphagia is common among the elderly, being 22% the prevalence in individuals over 50 years (8). 13% of patients in short-term-care hospitals and up to 60% of nursing home occupants have feeding difficulties (9).

Swallowing problems may have a series of physical consequences including dehydration, malnutrition, and respiratory infections, but are less well understood in terms of their social and psychological consequences. Eating and drinking are social and pleasurable experiences for healthy people, but patients with dysphagia may become isolated, feel excluded by others, and be anxious and distressed at mealtimes(9).

It is often challenging to assess the cause of the symptoms and it may require a multidisciplinary approach, that often starts with an ENT and neurological evaluation, followed by videofluoroscopy and/or oesophageal-gastro-duodenoscopy. When such examinations are done, other investigations may be appropriate: manometry in combination or not with impedance and videofluoroscopy, pH monitoring, ultrasonography and electromyography (10, 11).

The pharyngoesophageal segment

The pharyngoesophageal segment is made up of three components: the distal part of inferior pharyngeal constrictor, the cricopharyngeus muscle (CPM) and the proximal part of the cervical oesophagus, Figure 1.

The CPM has a superior portion, the pars obliqua, closely connected to the inferior pharyngeal constrictor. The middle horizontal portion of the CPM, the pars fundiformis, is a C-shaped muscle, attached to the lateral laminae of the cricoid cartilage which encircles the entrance of the oesophagus(4). It is sometimes separated from the pars obliqua by a triangular area called Killian's dehiscence, characterized by its scarcity of musculature, present in 30 % of individuals and is the typical location of Zenker's diverticulum (12). The inferior part of the CPM, the pars longitudinalis, attached to the inferior part of the cricoid cartilage, converges with the longitudinal muscle bundles of the proximal oesophagus. The term CPM will be used in this thesis to designate the middle portion of the muscle, Figure 1.

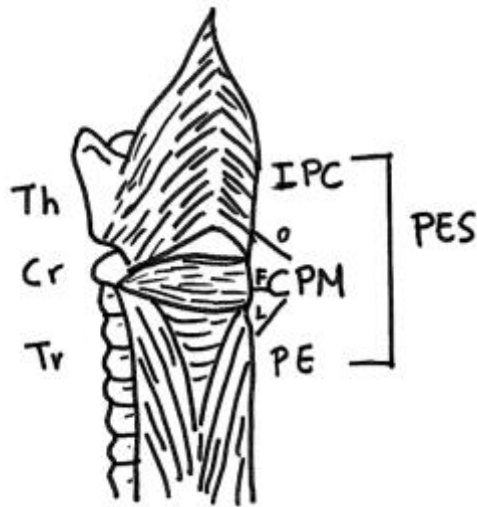


Figure 1.

Anatomy of the pharyngoesophageal segment. Th= thyroid, Cr= cricoid, Tr= trachea, IPC= inferior pharyngeal constrictor, CPM= cricopharyngeus muscle (O= obliqua, F= fundiformis, L=longitudinalis), PE= proximal oesophagus, PES= pharyngoesophageal segment

Human pharyngeal constrictors appear to be organized into functional fibre layers. The slow, inner layer, innervated by the glossopharyngeal nerve (IX), appears to be a specialized layer unique to humans to maintain the stiffness of the pharyngeal walls during respiration and to shape the walls for speech articulation. In contrast, the fast, outer layer, innervated by the vagal nerve (X), is adapted for rapid movement as seen during swallowing (7). The vagal nerve innervates the inferior pharyngeal constrictor through the external superior laryngeal nerve and the pharyngoesophageal nerve forming the pharyngeal plexus. The innervation of the CPM is derived from two different parts of the vagal system: One is associated with the pharyngeal origin (the pharyngeal plexus) and the other with the laryngeal development (the recurrent laryngeal nerve). The contraction of the CPM during inspiration and phonation reflects segmental laryngeal origin, the contraction during the pharyngeal phase of swallowing expresses pharyngeal origin. Sensory innervation is provided mainly by the glossopharyngeal nerve (13).

The PES is closed between swallows to prevent swallowing of air during inspiration and phonation and to protect the airway against aspiration of refluxed gastric and oesophageal content(12). It relaxes during swallowing and participates in pharyngeal contraction which cleans the pharynx at the end of the swallowing process (1). Thus, the PES is contracted at rest and relaxed during deglutition, burping and vomiting. It presents reflexive contraction during various types of stimulation e.g. by injection of minute amounts of water into the pharynx (14, 15).

Five phases have been described in PES opening. It starts with the inhibition of PES contraction (phase 1), then the hyoid and larynx move upwards and forward to provide passive opening of the PES (phase 2), the bolus, propelled by the tongue and the pharynx, distends the PES (phase 3) and after the bolus passes through, the PES collapses passively (phase 4) and finally (phase 5) it closes through active contraction (16).

Cricopharyngeal dysfunction: concept, diagnosis and treatment

Cricopharyngeal dysfunction (CPD) is defined as a reduction in the maximal opening of the UES during transphincteric flow (17). This can be seen during videofluoroscopy as a posterior impression into the PES, at the level of C5-C6, figure 2. This condition has been described as a cricopharyngeal bar and is often referred to as cricopharyngeal or cervical achalasia (18). Explanations of the origin of this bar include defective relaxation of the CPM, fibrosis and muscle hypertrophy. The CPD is seldom an isolated phenomenon, it is commonly associated with abnormal motor function in the segment above it (i.e., the inferior pharyngeal constrictor) and/or in the segment below it (i.e., the cervical oesophageal muscles). CPD is relevant in the pathogenesis of Zenker's diverticula (19). Incoordination of the PES rather than spasm of the CPM is present in these patients (20, 21). CPD is characterized by dysphagia, frequent aspiration and functional narrowing at the level of the PES (22). Only patients with more than 50 % indentation present narrowing of the anteroposterior diameter at the level of the cricopharyngeal bar and require treatment (18, 23).

Videomanometry gives a direct comparison of pressure readings and dynamic anatomy, and is therefore an ideal method to evaluate CPD. UES opening is best evaluated radiologically and relaxation manometrically, which means that these procedures complement each other. Videomanometry can help in the investigation of the interrelation between two abnormal findings, for instance, non-relaxation of the UES and reduced laryngeal, superior-anterior movement. Subtle abnormalities of muscle function, not visible on videofluoroscopy, can become evident in pressure information at early stages of the disorder. The presence of residue and aspiration is best visualized by videofluoroscopy (24).



Figure 2.
Lateral view of the posterior Cricopharyngeal indentation

Treatment of CPD includes dietary modifications, rehabilitative swallowing treatment and surgery. Patients with CPD swallow fluid of thin and slippery consistency better than thick, viscous or solid food. Before making any dietary modifications, great care should be taken to evaluate laryngopharyngeal sensation to avoid aspiration. Patients with poor laryngeal elevation and inadequate pharyngeal strength make poor surgical candidates, whereas those with inadequate relaxation of the CM but normal pharyngeal strength and laryngeal elevation, respond well to surgery (25). Rehabilitative swallowing treatments, the Shaker exercise and the Mendelsohn manoeuvre, play an important role in the CPD treatment. The Mendelsohn manoeuvre consists of holding the larynx in an elevated position for several seconds during swallowing, this prolongs laryngeal elevation and helps to open the PES. To perform the Shaker exercise, the patient lies flat,

keeps his shoulders on a bed/mat, and raises his head to look at his toes. The patient maintains this position for 60 seconds and then repeats this movement 30 times. This suprahyoid muscle-strengthening exercise facilitates the opening of the UES (26, 27).

Regarding the surgical treatment of CPD, the cricopharyngeus muscle is the major anatomically identifiable component of the PES and usually the target for intervention. There are four approaches to CPM, including: (1) myotomy of the CPM using an external technique, which is indicated when a muscle biopsy or neck exploration is needed; (2) the endoscopic myotomy of the CPM, using CO₂ laser or the surgical stapler (this only in the presence of the Zenker diverticulum); (3) bougie or balloon dilatation (BD) of the UES, a low-risk option that is an attractive alternative to myotomy, especially in elderly patients with comorbid disorders that increase the risk of anaesthesia- and surgery-related complications and (4) botulinum toxin injection into the CPM transcervically or endoscopically (25, 28, 29).

Larynx cancer, total laryngectomy and alaryngeal voice

During the period 2008-2012, 902 new cases of larynx cancer were diagnosed in Sweden, according to the Swedish quality register for head and neck cancer, which means 180 cases per year. The gender distribution was 82% male and 18% female. The median age at diagnosis was 68 years. The majority of the tumours were localized to the vocal fold plane. Supraglottic and, in particular, subglottic localizations are unusual (30).

Despite the increasing use of organ preservation strategies in the treatment of laryngeal cancer, predominantly radiotherapy or CO₂ laser resection, total laryngectomy (TL) is unavoidable in patients with advanced or recurrent disease.

During a TL the entire larynx, the hyoid bone and the first two or three tracheal rings are removed. The trachea is diverted forward to the neck and sutured to the original skin incision or to a separately created skin incision. The inferior pharyngeal constrictor (that was previously attached to the larynx) and the pharyngeal mucosa are closed to re-establish the digestive tract. However, not all TLs are carried out in a similar way, the surgeon will choose a specific type of pharyngeal closure: in three or two layers (depending on the inclusion or not of the muscle) in a vertical line (I-shape) or in a T-shape. The surgeon may make a primary tracheoesophageal (TE) puncture and place a voice prosthesis and may carry out additional procedures, such as a myotomy, that influence tonicity of the neoglottis, or may construct the tracheostoma differently. All these differences may influence voice, speech and swallowing (31-33).

According to the Swedish protocol for the treatment of head and neck cancer, all treatment centres have a programme for rehabilitation after TL. Before treatment,

patients should be informed about the proposed treatment and its consequences. The preparatory work requires a multidisciplinary team which often consists of a physician, a speech therapist, a contact nurse and a social worker or psychologist. A stoma in the neck means that the patient must also adapt certain activities, such as showering and bathing. The period immediately after the operation is for many particularly difficult and mentally exhausting. It is imperative to consider carefully the rehabilitation of the physical and psychosocial side effects of this mutilating surgery (30).

The goal of the rehabilitation is to provide the patient with a functional mode of communication in everyday situations. The options available are tracheoesophageal speech, electrolarynx or oesophageal speech, see table 1. Most patients are provided with a voice prosthesis placed in a surgically produced fistula between the trachea and the oesophagus. Tracheoesophageal voice is regarded to be a more successful mode of restoring communication after TL than oesophageal and electrolaryngeal voice techniques, with success rates of up to 90%(34). It resembles the mechanism of normal laryngeal speech production(35). The difference lies in the source of the voice, Table 1.

The quality and intelligibility of a TE voice, is highly variable among patients (36), the anatomy and physiology of the PES play important roles and those patients who have undergone reconstruction of the pharynx in combination with total laryngectomy have less optimal voice (36). Other factors that influence the aerodynamics of alaryngeal voicing are the airflow through the voice prosthesis and the contact between the oesophageal end of the prosthesis and the posterior oesophageal wall (37).

Table 1.
Initiator, voice source, and resonator of laryngeal and alaryngeal voice.

	Laryngeal	Tracheoesophageal	Oesophageal	Electrolarynx
Initiator	Pulmonar air	Pulmonar air	Oesophageal air reservoir	Battery
Voice source	Glottis	PES	PES	Vibrating membrane
Resonator	Vocal tract	Vocal tract	Vocal tract	Vocal tract

We use the term “tracheoesophageal prosthesis” (TEP) inspite of the fact that the term “voice prosthesis” is paradoxical as the prosthesis itself does not actually generate sound. A variety of different TEPs is available and they can be divided into 2 main categories: nonindwelling voice prostheses, that are removed, cleaned and reinserted by the patient, and indwelling prostheses that remain in situ until replacement is necessary which must be done by a medical professional. In essence, a TEP is a one-way valve, presented as a hinged flap close to the oesophageal flange,

Figures 3-4. It is inserted into a fistula between the trachea and the oesophagus, usually created during the TL procedure. The one-way valve principle allows air to flow into the oesophagus and then into the PES after the stoma has been closed. It prevents fluids, food or saliva from entering the trachea and lungs, Figure 4. The TEP has retain-flanges at each end to secure the prosthesis and facilitate placement. At the time of the insertion, the tracheal end of the prosthesis has a safety strap attached, Figure 3. The thickness of the tracheoesophageal wall varies among individuals and therefore the length of the TEP must also be variable.



Figure 3.
Tracheoesophageal prosthesis.

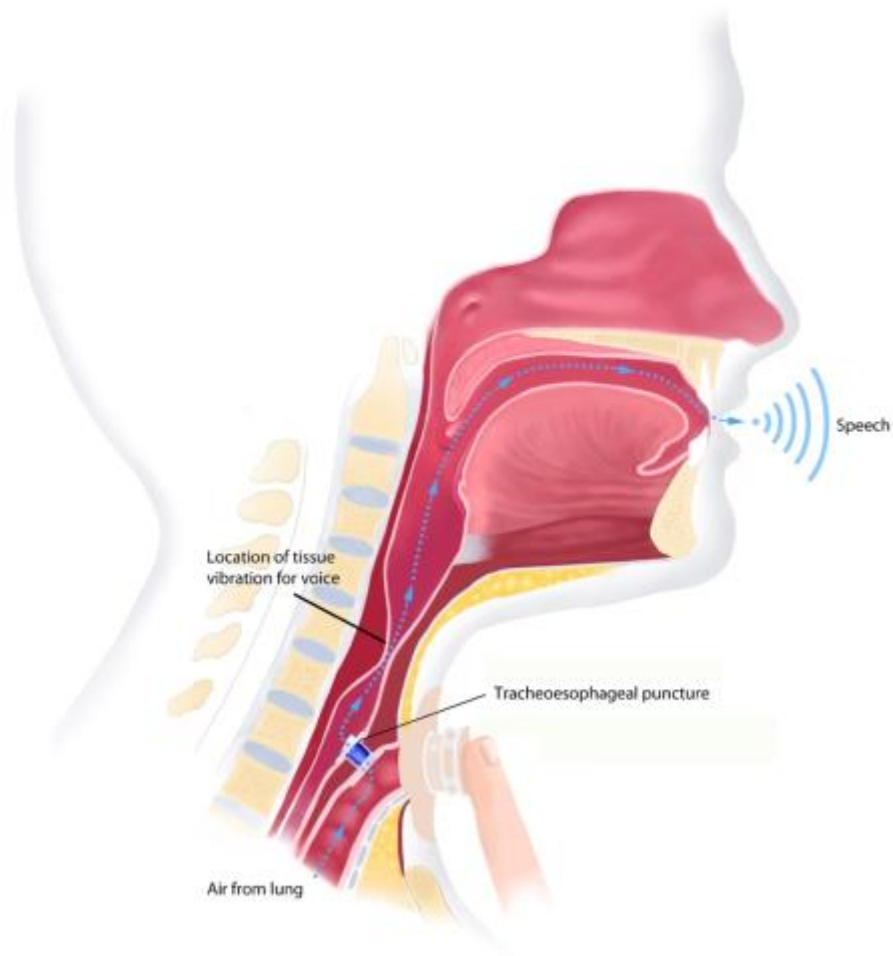


Figure 4. Tracheoesophageal speech. By courtesy of Atos medical.

Videomanometry: past, present and future

Oesophageal manometry has been used extensively as a test of oesophageal function for more than 100 years (38). Videomanometry uses manometry and videofluoroscopy simultaneously. The manometric device consists of a pressure sensor and a transducer that detect pressures and transform them into electrical signals. The pressure sensors and transducer components of a manometric assembly are available in two general designs: either water-perfused catheters with volume displacement transducers or electronic transducers with solid-state sensors. They are attached to a device to amplify, record and store the signals. Manometry records intraluminal pressure activity and detects and quantifies changes in intraluminal pressures caused by contractions of the muscles of the pharynx and the oesophagus. Such intraluminal pressures can be described as either contact pressures, when the manometric sensor is in direct contact with the pharyngeal wall, or cavity pressures, when the sensor is completely surrounded by air or fluid. The latter is also called intrabolus pressure (39). Pressure rate changes are greater in the pharynx than in the oesophagus, which means that the requirements for an accurate recording of pharyngeal pressures is a system with a minimum response of 4000 mmHg/s. This explains why solid-state sensors are preferred for accurate manometric recordings of pharyngeal pressure waves (24).

Manometry reflects the function of muscular components of the swallowing process and may therefore reveal subtle abnormalities in the swallow not apparent on videofluoroscopy. But manometry alone cannot provide information about the oral phase of swallowing, or about residue and aspiration or the cause of their occurrence, which makes it difficult to distinguish, for instance, a premature bolus spillage (due to reduced oral control) from aspiration caused by a pharyngeal disorder. This is best visualised by videofluoroscopy (24).

Early manometry systems included three to eight pressure sensors spaced 3–5 cm apart. Most of these devices had unidirectional sensors. This is particularly problematic for pharyngeal manometry, since the pharynx is characterised by circumferential asymmetry (14, 20). The development of high-resolution manometry (HRM) has been a major breakthrough. HRM includes catheters in which circumferential pressure sensors are closely spaced (no more than 1 cm apart), Figure 5. Thus, pressure information is obtained from the pharynx to the distal oesophagus with only one catheter placement. These systems are therefore not only more accurate but also more acceptable to the patient. Sphincters are clearly distinguished from adjacent regions and relaxation can be accurately quantified as the residual pressure within the spatial domain of the UES, Figure 6. Computer software enables the simultaneous recording of manometry and videofluoroscopy, producing a data file that allows easy access to pressure topography and time-matched fluoroscopic images, which facilitates the analysis and is known as high-resolution videomanometry (HRVM) (24, 40). Based on the metrics of the

oesophageal function, a classification of oesophageal motility diagnosis was proposed. This is the Chicago Classification of oesophageal motility disorders.



Figure 5.
The HRM catheter.

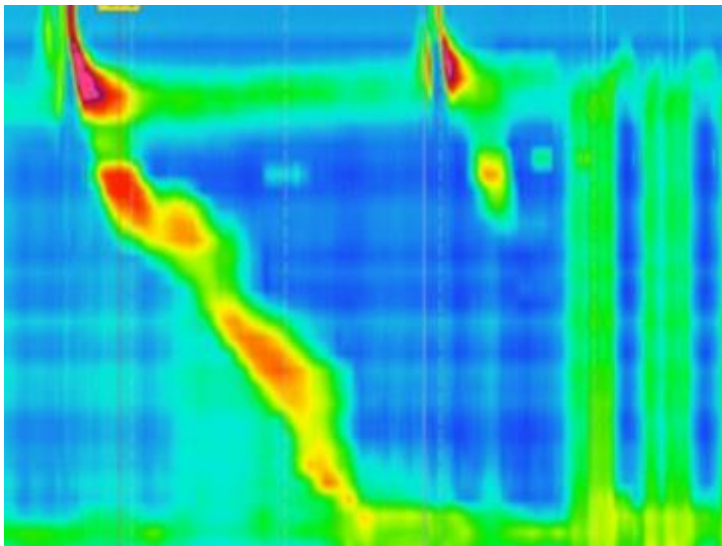


Figure 6.
Swallowing and phonation after total laryngectomy in a functional TE speaker, represented by HRM's topography plots.

Since the development of this classification in 2008, it has been periodically updated by an international working group to incorporate ongoing clinical and research experience (40-42). There is no such classification on the upper oesophagus sphincter (UES), thus there is a need to conduct studies combining HRM and videofluoroscopy to obtain standardised values of the pharyngeal swallow to measure not only UES function but also pharyngeal bolus propulsion forces (24).

The incorporation of multiple impedance sensors in HRM catheters in the past decade, to detect the presence of air or liquid by measuring changes in electrical resistance, allows the simultaneous measurement of bolus transit and bolus clearance in relation to pharyngeal and oesophageal pressures(43). This has revealed not only acid reflux, but also reflux events composed of gaseous and less acidic mixtures. It has led to high-resolution impedance manometry. This is particularly useful in the assessment of gastroesophageal reflux that does not respond to proton-pump inhibitor therapy, with regurgitation as a predominant symptom (40). Impedance has the advantage of not involving radiation exposure but, unlike videofluoroscopy, it does not estimate bolus volume, does not provide anatomic detail and does not detect associated aspiration. The most complete tool for the assessment of the swallowing process, in the near future, may be the high-resolution impedance videomanometry.

Laryngeal high-speed videoendoscopy

During phonation, the vocal folds usually open and close over 100 times per second and vibrate at velocities approaching 1 metre per second, making it impossible to view this activity with the unaided eye. Since the 1960s, stroboscopy has been the golden standard to evaluate vocal fold vibration (44). It uses a synchronised, flashing light passed through a flexible or rigid telescope. The flashes of light from the stroboscope are synchronised to the vocal fold vibration at a slightly slower speed, allowing the observations of the vocal fold vibrations during phonation in what appears to be slow motion. This slow-motion picture is an illusion, derived from many successive vibration cycles. But it is not sensitive enough to capture cycle-to-cycle variations in vocal fold vibrations and it is dependent on a stable phonation frequency. Usually the frequency of the strobe motion is about 1–2 Hz. Thus, a phonation of >1 s is needed to observe one vibratory cycle with stroboscopy. Aperiodic vibration causes the strobe light to become unsynchronised with the actual phase of vocal fold movements and prevents visualisation in “slow motion.” As a result, videostroboscopy cannot be used for tasks involving coughing, throat clearing, laughing, and other rapid laryngeal manoeuvres, as well as phonatory breaks, tremor, laryngeal spasms, alaryngeal voice, severe dysphonia and the onset and termination of phonation(45). High-speed videoendoscopy systems overcome these limitations, because they capture the intracycle vibratory movement by photographing the fast-vibrating vocal folds at speeds several times faster than the frequency of vibration, presenting those full-frame images of the vocal folds to the human eye at significantly slower rates. They are not dependent on the speaker’s fundamental frequency, which makes them ideal for the recording of laryngectomees’ voice (46). Kymography represents one section on the anterior-posterior plane of the vocal folds or the neoglottis, which is extremely useful in the assessment of vibration regularity, Figures 7 and 8, of laryngectomees one with good and one with poor voice quality.

Major advances have been made in high-speed imaging technology in recent years in order to couple rigid and flexible endoscopes with sensitive, solid-state image sensors to accomplish high-quality laryngeal high-speed videoendoscopy (47, 48). Today, high-speed endoscopy is the most powerful tool for the examination of vocal fold vibration and in voice research.

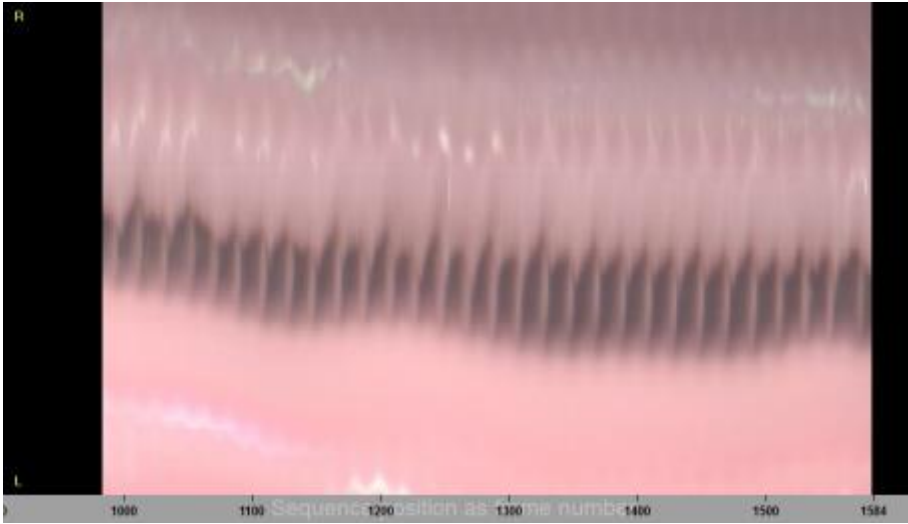


Figure 7. Kymography representing the PES of a laryngectomee with good voice quality. By courtesy of Dr. Rydell

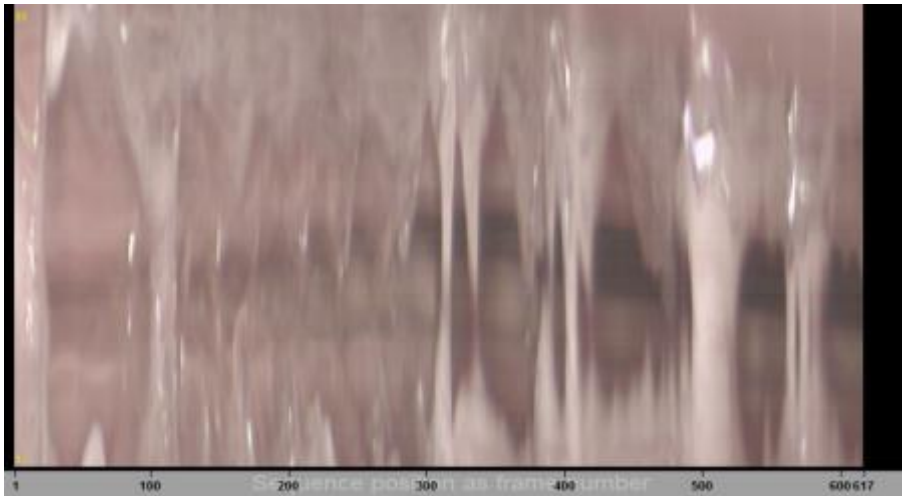


Figure 8. Kymography representing the PES of a laryngectomee with poor voice quality. By courtesy of Dr. Rydell

Perceptual voice assessment after total laryngectomy

Voice assessment requires a multidimensional approach to determine whether a voice is classified as normal or pathologic and to track changes in voice over time. Ideally, it should include perceptual evaluation combined with acoustic, imaging and patient self-report measures. Audio recording is a basic requisite for voice quality assessment. The microphone should be placed 10 or 15 cm from the mouth in order to calibrate the Sound Pressure Level and a standard text should be used. Voice quality is primarily a perceived phenomenon, which makes perceptual voice evaluation an essential item in voice assessment. Perceptual voice assessment in a scientific setting is time-consuming, requires a group of raters with experience and should follow a standard procedure (49-51). If only one variable is used to assess voice quality, naive listeners have shown good reliability (52). Several protocols for perceptual voice rating have been described, two examples are the GBRAS scale (G= grade of hoarseness, R= roughness, B= breathiness, A= asthenicity, S= straineness) proposed by Hirano et al. 1981(53), which uses a four-point scale, and the Stockholm voice evaluation approach (SVEA), which uses a 100mm visual analogue scale in 26 or 14 voice variables(54-56). Both protocols have been used not only in studies on various laryngeal voice disorders, but also in laryngectomees (56, 57). A main consideration in voice assessment in TE voice is that it should be compared with "near normal laryngeal voicing" rather than normal laryngeal voicing (58). Alternative protocols specific for the evaluation of alaryngeal voice are the INFVo (impression, intelligibility, noise, fluency and voicing) scale, in which ratings are scored between 0 and 10 and this gives a more accurate evaluation of laryngectomies than the GBRAS scale (59), and the Sunderland tracheoesophageal voice perceptual scale, with focus in the "Overall grade" of voice quality and "Neoglottal tonicity", according to which severe hypertonicity and hypotonicity equally relate to a poorer "Overall grade" (58).

Another important issue in perceptual voice evaluation is the intra/inter-rate reliability to check whether the ratings are reliable for further evaluations (51, 58). The reliability of the raters depends on their professional experience, the type of voice pathology being investigated and the type of speech material. Agreement among clinicians is usually higher for normal voices than for pathological voices and reliability may be improved by training and practice (51).

Voice and swallowing questionnaires in Swedish

Self-report questionnaires are commonly used to assess the patient reported outcome and the need for rehabilitation services. They guarantee that questions are asked in a standardised manner. Currently, excluding the SSQ, there are three

validated questionnaires in Swedish to assess dysphagia: the Swallowing Quality of Life Questionnaire (Swal-QOL) (60-62), the M. D. Anderson Dysphagia Inventory (MDADI)(63, 64) and the Eat-10(65, 66).

The Swal-QOL is intended to assess the quality of life in individuals with oropharyngeal dysphagia. It consists of 44 items and is divided into eleven subscales. The answers are given on a five-point scale where 1 is "always" and 5 corresponds to "never". The total score is between 0 – 100. The MDADI is another form of self-assessment of quality of life in individuals with oropharyngeal dysphagia who have undergone treatment for head and neck cancer. It consists of 20 items, which are estimated on a five-point scale. It is divided into four subscales: global, emotional, functional and physical. The clinician summarises the raw scores and calculates their mean value, which is then multiplied by 20, so that the total MDADI scores can be 0 - 100. For both, the Swal-QOL and the MDADI, the higher the score, the better the quality of life experienced by the respondent. The Swedish validation of the MDADI shows that it can also be used for people with neurological diseases(64).

The EAT-10 measures the physical, physiological, affective, mental and social impact of dysphagia. The EAT-10 consists of 10 items, is relatively easy to score and is designed for patients with oropharyngeal well as oesophageal dysphagia. The answers are given on a five-point scale where 0 is "no problem" and 4 correspond to "major problems". The total score can be 0-40. The higher the score, the greater is the perceived discomfort. A total score of ≥ 3 is considered abnormal(65).

Regarding to voice assessment after TL, the Voice Handicap Index (VHI), originally developed by Jacobson et al., has been translated and validated into Swedish (67, 68). The occurrence of symptoms is estimated on a frequency-based scale (0 = Never, 1 = Seldom, 2 = Sometimes, 3 = Often, 4 = Always). The total score can be 0-120. It has been used on laryngectomees to investigate the relation between VHI and quality of life, and VHI and perceptual and acoustical analyses of TE speech (56, 69). The VHI-T is a version of the VHI, which covers the three domains of the VHI (physical, functional, emotional) and includes a throat subscale. Each subscale scores range from 0 to 40, thus the total maximum VHI-T score is 160(70). The higher the score of the VHI and VHI-T, the greater is the perceived voice handicap. The Self Evaluation of Communication Experiences after Laryngeal Cancer (SECEL) has been validated into Swedish (71-73). It contains 35 items, 34 of these items are aggregated into three subscales that are hypothesised to measure general (score range 0-15), environmental (score range 0-42) and attitudinal (score range 0-45) voice experience, as well as a total score. Each item is rated on a 4-point category scale ranging from 0 (never) to 3 (always), and covers the preceding 30 days. Total score ranges from 0 to 102 points. A higher score indicates greater perceived communication dysfunction. Item no. 35: 'Do you talk as much now as before your laryngeal cancer?' is answered by three response categories (Yes; More; Less) and is not included in the scoring system. It has been used to address communication dysfunction in patients with larynx cancer (71).

Materials and methods

Paper I

The Sydney Swallowing Questionnaire (SSQ) is a self-report inventory with a maximum total score of 1700 (74). A visual analogue scale appears immediately beneath all but one question (Q12), yielding a score of 0–100 for each, Appendix 1 and 2. The Swedish version of the SSQ was used on 20 subjects without swallowing problems and on 20 patients with swallowing problems, both groups matched for age and gender. None had undergone previous head & neck surgery or radiotherapy that might have influenced their swallowing function.

After inclusion in the study, patients were assigned a Dysphagia Outcome and Severity Scale (DOSS) score (75). This is a 7-point scale developed to systematically rate the severity of dysphagia based on a videofluoroscopic swallow study. Score 7 indicates normal swallowing and score 1 indicates severe dysphagia.

Those responsible for the present study have received formal approval for the translation and validation from the lead author of the SSQ. The authors made a first translation from English to Swedish. In phase two, the items with divergent translations were discussed until a consensus was reached. In phase three, the SSQ was translated back to English by a native English speaker and linguist. In phase four, the SSQ was translated back into Swedish and a pilot group of four patients with swallowing disorders and four healthy subjects completed the questionnaire. In phase five, some of the formulations in the Swedish version of the questionnaire were altered according to the comments of the pilot group.

Paper II

We included eight patients who had dysphagia for more than 3 months, due to CPD. None had undergone any previous interventions in the PES. They were randomized to be treated either by laser myotomy (LM) or balloon dilatation (BD) and were assessed pre-treatment and 1 and 6 months post-treatment using videomanometry and the Swedish version of the SSQ.

The videomanometry (VM) system consisted of a simultaneous videofluoroscopy and conventional solid-state intraluminal manometry system. The catheter had a

diameter of 4.6 mm and 4 solid-state pressure sensors positioned 2 cm apart (Konigsberg Instruments inc. Pasadena, California, USA). The proximal sensors were oriented dorsally to measure through 120°, while the two distal transducers were circumferential, allowing measurements through 360°. The sampling frequency was 64 Hz. All pressure values were registered in mmHg and referred to atmospheric pressure. VM was performed in frontal and lateral projection with the patient seated. Videofluoroscopy was done before inserting the catheter, to measure the dimensions of the PES. A small amount of topic anaesthetic (Xylocain 2%; Astra Zeneca, Södertälje, Sweden) was placed in the nostril. All participants were instructed to swallow 10 ml of non water-soluble medium contrast (Omnipaque, 240 mg/ml, Nycomed Imaging, Oslo, Norway) three times. Retention and penetration of the contrast medium, resting, residual and contraction UES pressures, frontal and sagittal diameter of the UES 15 mm over and under the CPM, pharyngeal pressure and intrabolus pressure at the level of the constrictor inferior muscle, maximal hyoid movement, laryngeal elevation, duration of UES relaxation and oesophagus amplitude were analysed by VM. Laser myotomy and balloon dilatation were performed under general anaesthesia.

Paper III and IV

Fourteen TE speakers, without swallowing complaints, who rated themselves as good or reasonable speakers, were recruited for paper III. Thirteen patients who reported themselves as non-functional TE speakers (no voice production, not able to talk on the telephone and/or phonasthenia) were recruited for paper IV; one patient died prior to treatment due to complications related to liver cirrhosis. Cricopharyngeal myotomy had been performed in the same session as the laryngectomy. Their treatment was terminated at least 3 months before they were included in the present study and presented no evidence of recurrent disease. Their stoma was covered with a heat and moisture exchanger valve. The patients were audio recorded while reading a standard text. Perceptual assessment was made by three experienced speech and language pathologist (SLP), independently, three times per patient to calculate intralistener and interlistener reliability. The SLPs registered six variables, based on the Stockholm Voice Evaluation Approach, which were modified according to the anatomy of the laryngectomees (54-56). For the first two variables, quality and intelligibility, three options were available: good (=1), reasonable (=2), poor (=3). For variables rough, breathy, hyper functional and gurgly, a visual analogue scale (VAS) was used, Appendix 3.

Videomanometry was performed using a high-resolution, solid-state transducer system (ManoScan-360, Sierra Scientific Instruments, Los Angeles / CA, USA). The catheter, 4.2 mm in diameter, had 36 sensors and every sensor contained 12 measuring points. It was introduced through the nose after applying topic

anaesthetic (Xylocain 2%; Astra Zeneca, Södertälje, Sweden) in order to reduce patient discomfort. All participants were instructed to swallow 10 ml of non water-soluble contrast medium (Barium contrast, 240 mg/ml, 60% weight/volume) three times. During swallowing several variables were analysed, namely, resting PES pressure, residual pressure during PES opening, pharynx contraction pressure 3cm cranial to the PES and oesophagus peristaltic contraction pressure. During phonation the pressure at the PES, pharynx, proximal oesophagus and distal oesophagus and the craniocaudal length of the PES were registered. The phonation index (phonation pressure at the PES/phonation pressure at the distal oesophagus) was calculated for the patients included in paper IV.

The high-speed camera examination consisted of a personal computer and a camera head used in combination with a 70° rigid endoscope (HRES Endocam, model 5562.9 colour, R.Wolf, Knittlingen, Germany) and a 300 W cold light source. We recorded 2000 frames per second. Patients were asked to produce a sustained /ae/ or /e/ sound. Two specialists in Otolaryngology and Phoniatics, blind to the clinical data, judged the recordings and made an assessment by consensus. The variables used for visual assessment of digital HSC recordings of the PES were: amount of saliva present at the neoglottis, neoglottis visibility and shape, vibration location, mucosal wave, vibration regularity and duration of the open or closed phase of the neoglottis in relation to the complete cycle of vibrations (36).

The patients included in paper IV were treated with Botulinum toxin (BT) and/or balloon dilatation (BD). Previous to the injection of the BT, topical anaesthetic with vasoconstrictor (Lidocain-Nafazolin APL 34 mg/ml + 0.17 mg/ml) was applied in the nostril and the patient swallowed lidocain (Xylocain viscous 20 mg/ml; Astra Zeneca, Södertälje, Sweden). We used an injection needle (Posi-Stop from Hobbs Medical inc.) through a channel fiberlaryngoscope, to inject the BT at three points in the visible cranial part of the PES. We used freshly reconstituted, purified botulinum toxin type A (Botox, Allergan Inc, Irvine, California) at a concentration of 2.5- mouse units (MU)/0.1 mL in a total dose of 30-50 units.

BDs were performed at the outpatient clinic. Topical anaesthetic with a vasoconstrictor (Lidocain-Nafazolin APL 34 mg/ml + 0.17 mg/ml) was applied in the nostril and lidocain (Xylocain 10 mg/ml; Astra Zeneca, Södertälje, Sweden) was sprayed into the throat to anaesthetise the pharynx. Dilatations were performed with controlled radial expansion balloons with diameters between 8-14 mm, over 2- 2.5 min through a channel fiberbroncoscope, Figures 9 to 11. The procedure was done twice in all patients, with a 6-week interval between dilatations.



Figure 9. Balloon used for dilatation of the PES. By courtesy of Dr. Wahlberg

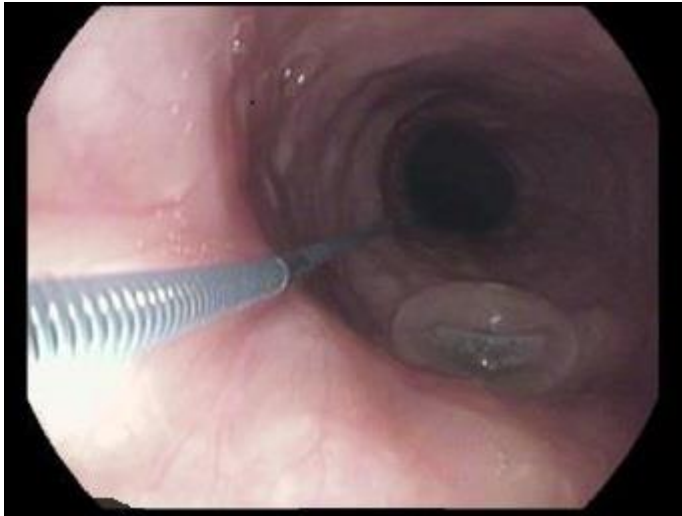


Figure 10. Balloon previous inflation at the PES, with a view of the tracheoesophageal prostheses. By courtesy of Dr. Wahlberg

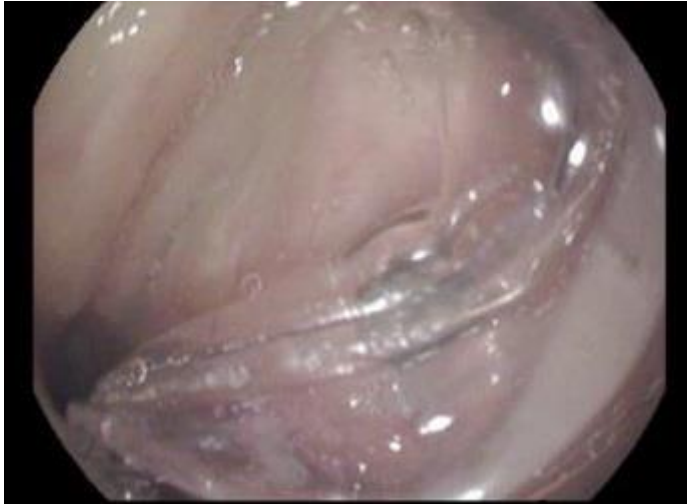


Figure 11.
Inflated balloon for dilatation of the PES. By courtesy of Dr. Wahlberg

Paper V

Patients who have undergone TL in the South of Sweden between January 2000 and June 2016, and who were alive at the time of the study were identified and invited to participate in the study by letter. Forty-five (36 men and 9 women) out of 61 invited patients accepted to participate and were included in the study. The Swedish version of the SSQ and the VHI-T were answered by the 45 patients included in the study. Two of the participants did not allow access to their medical records. All patients were assessed pre- and post-operatively by a nutritionist and a speech- and language- pathologist. Eight participants had undergone a neck dissection and all had undergone standard TLs except one case of hypopharynx cancer, which required extended excision of the tongue base and a microvascular flap. Myotomy of the cricopharyngeus muscle and pharyngeal closure in three layers was described in all cases except four patients. Primary insertion of the TEP was performed in all patients.

The VHI-T is a version of the VHI, which includes physical, functional, emotional and throat subscales. It consists of forty statements, ten in each domain. The occurrence of symptoms is estimated on a frequency-based scale (0 = Never, 1 = Seldom, 2 = Sometimes, 3 = Often, 4 = Always). Each subscale scores range from 0 to 40, thus the total maximum VHI-T score is 160(70). To describe the self-perceived voice quality, a 10 cm Visual Analogue Scale (where 0 = no voice problems and 100 = maximal voice problems), was included.

SSQ scores were calculated as recommended in the Swedish validated version. A high VHI-T and SSQ score represents severe dysphagia and/or severe voice handicap.

Statistics

All data were analysed using the Statistical Package for the Social Sciences (SPSS) 22 and 23 © Mac version. P values ≥ 0.05 (two-tailed) were regarded as significant.

Paper I

We evaluated the validity of the content, and the construction, as well as the discriminant and predictive validity and the test-retest reliability (74). Content validity reviews whether the questions in the questionnaire are appropriate for the intended use of the SSQ. The underlying relationships between the questions were analysed by factor analysis. Construction validity refers to whether an instrument measures the true clinical state of the patient. In this case, is the SSQ adequate to measure dysphagia? We hypothesised that the DOSS correlated with the SSQ and used Spearman's non-parametric correlations to confirm this. Discriminant validity measures the ability of the SSQ to distinguish clinically significant differences in pre- and post-operative scores. We compared the SSQ score, using the Wilcoxon signed rank test, pre-operatively and 4 weeks post-operatively in 4 patients with Zenker's diverticulum treated with staple myotomy and in 6 patients with cricopharyngeal dysfunction, treated with balloon dilatation. Predictive validity refers to whether SSQ can differentiate between patients with dysphagia and normal swallows. We used the Mann Whitney U test to evaluate the predictive validity. The test-retest reliability measures the ability of the SSQ to yield consistent scores over time. We evaluated the variability of the score over 3 weeks using the Intraclass Correlation Coefficient (ICC).

Paper II

Statistical analysis was done using descriptive statistics. ANOVA repeated measures were used to compare results pre-operatively, with 1 and 6 months post-operatively.

Paper III and IV

ICC were calculated to assess intra- and inter-rater reliability. The Wilcoxon signed rank test was used to compare results pre- and post- treatment.

Paper V

The statistical descriptive analyses are presented as mean, standard deviation and median. The Spearman correlation test (r_s) was used for correlations between VHI and SSQ scores and time after TL, age, frequency of TEP change. Fisher's exact test was used to compare SSQ and VHI-T depending on the T stage.

Ethical considerations

All studies comply with the World Medical Association's Declaration of Helsinki, ensuring integrity and autonomy of all participants. All studies included in this dissertation gained ethical approval by the regional Ethical Review Board at Lund University, Sweden. Participants in all studies gave informed written consent for participation.

Results and Discussion

The purpose of this thesis was to study the PES in patients with oropharyngeal dysphagia (papers I-II) and patients with tracheoesophageal speech after total laryngectomy (papers III-V). The assessment of these patients was made by a multidisciplinary team with a clinical evaluation combined with a self-report instrument which was used to capture the patients' perception of the symptoms (paper V).

Paper I: Validation in Swedish of the Sydney Swallow Questionnaire

A patient-assessed outcome measures the severity of a symptom/disease, taking into account social, functional and psychological issues (76). The aim of this study was to translate and adapt the SSQ to Swedish conditions, and evaluate the validity and test-retest reliability of the SSQ in Swedish in patients with oropharyngeal dysphagia and in healthy controls. The method used to translate the SSQ from English to Swedish, named forward- and back translation, is well established. The forward- and back translation may be criticised not only because it is time consuming, but also because the translation is made by physicians and a professional translator. The language used in the questionnaire may be difficult to understand for the patients. Therefore, we let a pilot group of 4 patients and four healthy people answer the Swedish SSQ before the translation process was completed (77, 78). The English and the Swedish final versions of the SSQ are presented in Appendix 1 and 2.

The relevance of the questions of the Swedish version of the SSQ (content validity), was confirmed by the factor analysis. The SSQ score increases, when the DOSS decreases ($r_s = -0.70$, $p < 0.001$). However, both measure the symptom dysphagia (construct validity). The ability of the SSQ to distinguish clinical differences in therapeutic responses over time (discriminant validity), was confirmed by the Wilcoxon signed ranks test ($p = 0.002$). The mean score for controls was 51 ± 30 and the mean score for patients was 638 ± 361 . Thus, as hypothesised, patients with dysphagia scored significantly higher on the SSQ ($p < 0.001$), which proved predictive validity. The cut-off score for dysphagia in the

Swedish version is 111, which is the result of the mean score of the healthy controls plus two standard deviations ($51+(2 \times 30) \geq 111$). Therefore, values higher than 111 should be considered as pathological. In the original SSQ the cut-off score would be $67+(2 \times 63) \geq 193$, which might be explained by differences in the Australian and Swedish control population. Finally, the test-retest reliability for patients' scores within 3 weeks, was confirmed by a 0.98 ICC. Thus, the Swedish version of the SSQ complies with the criteria for content, construct, discriminant and predictive validity and test-retest reliability. This guarantees that questions are asked in a standardised manner, and gives valuable and comprehensive information about oropharyngeal dysphagia.

Paper II: Treatment of Cricopharyngeal Dysfunction

Cricopharyngeal dysfunction (CPD) is defined as the reduction in maximal opening of the UES during transphincteric flow (17). Before any treatment, it is important to assess the pressure and dynamic anatomy of the UES. In the present study, videomanometry was performed pre-operatively and 1 and 6 months post-operatively, and the oropharyngeal dysphagia was scored using the SSQ.

After being randomized, four patients were treated with BD and four with LM. The mean SSQ score pre-operatively was: 770 (BD: 691, LM: 850), 1 month post-operatively: 340 (BD: 398, LM: 281) and 6 months post-operatively: 559 (BD: 718, LM: 399) which confirmed the improvement in self-reported dysphagia ($p = 0.003$). We could not find a difference between treatments ($p = 0.72$).

The highest pre-operative mean scores (>50) were registered for seven questions: difficulty in swallowing hard food (Q5), difficulty in swallowing dry food (Q6), food getting stuck in the throat (Q9), choking on solid food (Q10), having to swallow more than once (Q14), dysphagia severity rate (Q16) and quality of life (Q17). Post-operative mean scores decreased in all these questions, with values ≤ 45 , Table 2.

Table 2.

Pre- and post-treatment Sydney Swallowing Questionnaire's mean scores by question

SSQ Score	Pre-op	Post-op1	Post-op2
1.Swallowing difficulty	36	17	40
2.Thin liquids	32	20	31
3.Thick liquids	26	20	34
4.Soft food	38	19	23
5.Hard food	64	18	42
6.Dry food	61	30	45
7.Swallowing saliva	23	12	17
8.Starting a swallow	47	17	34
9.Food sticking in the throat	65	28	45
10.Coughing/choking with solids	60	22	40
11.Coughing/choking with liquids	35	19	26
12.Time to eat a meal	33	28	30
13.Food/liquid behind nose	25	12	16
14.Swallowing more than once	58	26	40
15.Coughing/spitting during a meal	44	20	28
16.Dysphagia severity rate	60	21	43
17. Quality of life	68	16	38
Total	770	340	559

VM showed that the UES sagittal diameter at the CPM increased regardless of the treatment offered, from a 5.6 mm pre-operative mean diameter (BD: 5.6 mm, LM: 5.6 mm), which represents an obstruction $\geq 50\%$, to 7.6 mm 1 month post-operatively (BD: 7.2 mm, LM: 8 mm) and finally to 8.4 mm 6 months post-operatively (BD: 8.1 mm, LM: 8,7 mm). We could not find a difference between the two treatments in our cohort. The increase of the UES sagittal diameter at CPM might explain that three patients (2, 5 and 8) did not present subepiglottic penetration post-operatively and that the tongue base pressure decreased from 261 mmHg pre-operatively (BD: 269 mmHg, LM: 250 mmHg), to 241 mmHg 1 month post-operatively (BD: 236 mmHg, LM: 249 mmHg) and finally to 187 mmHg 6 months post-operatively (BD: 178 mmHg, LM: 200 mmHg). No other variables changed post-operatively.

Three patients (number 3, 5 and 6) had retention of the contrast in the vallecula pre- and post-operatively. This might suggest that dilatation and weakness of the pharynx related to prolonged outlet obstruction do not change after treatment. The resting, residual and contraction UES pressures were within the normal range as described by Olsson et al. (18). Thus, CPD was associated with abnormal function of the pharyngeal constrictors which caused incoordination of the PES rather than spasm of the CPM (18, 20).

VM displays only sagittal and frontal images of the PES. The addition of impedance measures (to obtain information on bolus flow and reflux) and cross sectional images of the PES using High Speed CT Scan and functional MR may provide additional information about this area. High Speed CT Scan displays 3D and axial images and allows a rate of only 10 frames / second (our videofluoroscopy has a rate of 25 frames/ second). It requires that the patient is sitting at 45 degrees, a position that is not quite optimal for swallowing. Functional MR does not expose patients to radiation, but it is time consuming. Therefore, these methods are not used yet in routine dysphagia assessment.

Papers III and IV: The Pharyngoesophageal Segment in Laryngectomees with Functional and Non-functional Tracheoesophageal Speech

In paper III we used voice perceptual assessment, HSC and high-resolution HRVM to characterise the PES of functional TE and to establish a baseline for normal TE function. In paper IV we used the same methods to characterise the PES of non- functional TE speakers and to assess the effects of treatment with botulinum toxin and/ or balloon dilatation. We recruited 14 functional TE speakers and 13 patients who reported themselves as non-functional TE speakers (no voice, not able to talk on the telephone and/or phonastenia). All patients underwent post-operative speech therapy.

The voice perceptual assessments made by the SLPs revealed high intra- and interlistener reliability except for the variable “breathy” in non-functional TE speakers (ICC= 0.29, p= 0.03). The values of the voice assessments of the functional TE speakers (paper III) were: 4 patients had good, 7 had reasonable and 3 had poor voice quality; 5 had good, 6 reasonable and 3 poor voice intelligibility. Regarding non-functional speakers (paper IV), 5 subjects had no voice before the treatment and the others were rated by the SLPs as: 1 had good, 4 had reasonable and 3 had poor voice quality; 2 had good, 5 had reasonable and 1 had poor voice intelligibility. Those patients who rated themselves as non-functional speakers received treatment, one died prior to treatment. Six received BT. Six had an anterior posterior diameter at the PES of less than 5 mm and reported dysphagia. Four were treated with BD

twice and experienced clinical improvement, and therefore they were not treated with BT. Two were treated with both BD and BT. After treatment, 8/12 patients reported clinical improvement in voice and dysphagia, four reported no clinical improvement, two of them left the study. We used variables from the Stockholm Voice Evaluation Approach (SVEA), for the assessment of laryngeal and alaryngeal voice. It has been used for alaryngeal voice rating by Lundström et al. (69). Alternative protocols specific for the evaluation of alaryngeal voice are the INFVo (intelligibility, noise, fluency and voicing) scale (59) and the Sunderland tracheoesophageal voice perceptual scale, with focus in the “Overall grade” of voice quality and “Neoglottal tonicity”. According to this, severe hypertonicity and hypotonicity equally relate to a poor “Overall grade” (58), which agrees with the fact that “hyperfunctional” was the variable with highest values in non-functional speakers, both before and after treatment.

In paper III, the group of patients with good/reasonable voice quality according to the voice assessment made by the SLPs, revealed a positive correlation between voice quality and voice intelligibility ($r_s = 0.8$ $p= 0.002$). In addition, a positive correlation between roughness and poor voice quality ($r_s= 0.6$ $p= 0.04$), hyperfunction and poor intelligibility ($r_s= 0.6$ $p= 0.04$), poor quality and long time since TL ($r_s= 0.7$ $p= 0.01$) and poor voice quality and old age ($r_s= 0.6$ $p= 0.05$) was found.

HSC is ideal for the assessment of the vibratory pattern of the neoglottis since it does not depend on the fundamental frequency of the voice. Recordings were obtained in all but two functional speakers (paper III), who did not tolerate the telelaryngoscope. The neoglottis was visible in all participants with good/reasonable voice, and the shape was circular in five of nine patients. Vibrations were seen in the whole circumference in six of nine participants, the vibration was regular in four and irregular in five patients. The mucosal wave was strong in eight of nine patients, the neoglottis remained predominantly open in four of nine participants. Six of nine patients had scant amount of saliva. These results highlight the variability in the morphology and function of the neoglottis after TL. In non-functional speakers, i.e. patients with no voice (paper IV), assessment with HSC could not be done. Seven patients were assessed before treatment with HSC and ten were assessed after treatment. The Wilcoxon sign rank test showed no difference between HSC recordings before and after treatment.

The values of the HRVM variables according to the assessment of the SLPs, in both studies, are presented in Table 3. HRVM showed low resting pressure at the PES (17-25 mmHg) and low oesophageal peristaltic contraction pressure (50-68 mmHg) during swallowing, which characterises laryngectomees in comparison to normal subjects (39, 79, 80). The pharyngeal contraction pressure was lower in functional speakers with good/reasonable voice (77 mmHg), than in non-functional speakers before treatment (168 mmHg), although both values are included in the normal range of pharyngeal contraction pressure of healthy volunteers (39). This might be explained by the presence of stenosis at the PES in the non-functional

speakers. A decreasing phonation pressure from the distal oesophagus to the pharynx was revealed in functional speakers and non-functional speakers after treatment. Non-functional speakers presented, before treatment, a higher phonation pressure at the PES than functional speakers (64 versus 39 mmHg). These values may indicate that a harmonious decreasing pressure along the entire oesophagus up to the PES and pharynx is necessary for a functional TE voice production (81). Thus, to improve TE speech we should consider not only the PES pressure, but also the pressure in the distal oesophagus. If the phonation pressure in the oesophagus is too low, the air from the lungs will descend into the stomach instead of setting the mucosa of the neoglottis into vibration. We proposed a phonation index, defined as the ratio between the phonation pressure at the PES and that at the distal oesophagus, which might explain the difference between a functional and a non-functional TE speaker. We aimed to reduce this phonation index by treating the PES of our patients with BT and/or BD. The phonation index of the non-functional TE speakers decreased after treatment, Table 3.

Table 3.

Pressures in functional speakers (paper III) and non-functional speakers (paper IV).

	Functional Good/reasonable speakers	Functional Poor speakers	Functional Speakers Takeshita*	Non- functional speakers Before treatment	Non- functional speakers After treatment
PES lenght	14 (10)	11 (10)		15 (15)	14 (15)
Phonation 1	22 (20)	7 (6)		48 (45)	36 (32)
Phonation 2	39 (34)	39 (41)	38	64 (64)	47 (45)
Phonation 3	39 (42)	58 (73)	43	55 (58)	47 (48)
Phonation 4	54 (42)	68 (88)	54	60 (60)	58 (64)
Phonation index	0.7	0.6	0.7*	1	0.8
Pharyngeal pressure	77 (54)	133 (48)		168 (169)	133 (128)
Resting pressure	17 (16)	16 (17)		25 (26)	23 (18)
Residual pressure	10 (5)	4 (4)		30 (27)	17 (15)
Oesophageal pressure	50 (36)	68 (47)		54 (40)	50 (32)

Mean values, the median value is presented in parenthesis. Phonation: PES = Pharyngoesophageal segment, Phonation1= Phonation pressure 3 cm cranial to PES, Phonation 2= pressure at PES, Phonation 3= Phonation pressure 3 cm caudal to PES, Phonation 4= Phonation pressure 7 cm cranial to lower oesophagus sphincter.

Phonation index= Ratio between the phonation pressure at PES and the phonation pressure at distal oesophagus. Swallowing: Pharynx pressure, Resting and Residual pressure at PES, Oesophageal pressures. *= This ratio and the functional speaker's phonation pressures are based on data from Takeshita et al. 2014.

PES hypertonicity is not the only component in TE speech failure, fibrosis at the PES and impaired oesophagus motility need to be considered. Stenosis at the PES and disturbance of the oesophageal peristalsis may account for up to 85% of self-reported dysphagia by the non-functional speakers included in paper IV.

Paper V: Voice and Swallowing after Total Laryngectomy

We studied the occurrence of swallowing and voice problems in patients who had undergone laryngectomy using the SSQ and VHI-T. Of 185 patients laryngectomised between January 2000 and June 2016, 68 were still alive. Forty-five (36 men and 9 women) of 61 invited patients accepted to participate and were included in the study. Mean age at the time of the TL was 66 ± 11 years and mean age at study inclusion was 72 ± 11 years. Thirty-nine of the patients used TE speech (86%), one esophageal speech and five electrolarynx. The mean frequency for TEP replacement was 12 ± 11 weeks, which was more often than in other studies (34). Mean time after TL was 77 ± 58 months. All patients except four, were treated with RT pre-, post- or pre- + post- TL and only 11 patients underwent a TL as primary cancer treatment. Only 3 patients (7%) presented pharyngocutaneous fistulas < 2 months after surgery, which is a low fistula formation rate when compared with 42% reported by another study (82).

We have chosen the VHI-T as self-report inventory, not only because VHI has been frequently used as self-assessment instrument after larynx cancer, but also because we were interested in the results that the throat subscale might show (56, 70). Though, the SECEL questionnaire could have been an option as well (83). The VHI-T mean value was 60 ± 35 . The two statements with the highest VHI-T score were those describing difficulties in making oneself heard and understood in a noisy room and difficulties to raise voice volume when needed. The statements with the highest score on the throat subscale were frequent throat clearing and excessive mucus in the throat, which did not differ from the symptoms reported by other patients with voice problems (70). The SSQ total mean value was 415 ± 322 . The four questions with the highest SSQ were those describing how difficult it was to swallow dry food (Q6), if food got stuck in the throat (Q9), if they needed to swallow more than once (Q14) and the question related to quality of life (Q17). These answers to these questions described the most frequent symptoms of oropharyngeal dysphagia which non-laryngectomized patients with CPD reported in paper II.

There was no correlation between age and SSQ scores or age and VHI-T scores, which differs from the data reported by Op de Coul et al (34). The scores of the VHI-T diminished as time increased after TL ($r_s = -0.3$ $p \leq 0.04$), because patients might not only improve their speech technique during their rehabilitation with the

SLP, but also adapt to their handicap. The SSQ score was not affected by the time passed after TL and patients who changed their TEP often reported more swallowing problems than those who did not ($r_s = -0.36$ $p \leq 0.01$). An explanation might be the presence of pharyngeal/gastroesophageal reflux after TL, which might shorten the life of the TEP and cause tracheoesophageal puncture failure (84), stenosis at the PES and dysphagia. Swallowing problems were reported by 89 % of the patients (using SSQ = 111 as cut-off), and moderate to severe voice handicap (VHI-T > 40) was reported by 66%. Thus, most of the subjects who had dysphagia also presented voice problems ($r_s = 0.67$ $p \leq 0.01$). Additional therapeutic interventions to manage problems with voice and/or swallowing after TL were required in 62% of the patients. The most common intervention was BD of the PES, 44% presented stenosis at the PES, 53% of them > 60 months after TL. The stenosis in all patients had been assessed by videofluoroscopy. Although the postoperative fistula formation rate was low and the majority of the pharyngeal reconstructions were closed in three layers and in vertical orientation(32), the high stenosis rate might be caused by extensive tumour resections and fibrosis post-radiation (most of the patients received > 60 Gy)(85).

During the past 20 years, much attention has been paid to the rehabilitation after TL. All centres, where laryngeal cancer is treated, have well-established, tobacco-cessation, voice and pulmonary rehabilitation programmes (86). Patients usually receive advice from a nutritionist and a SLP pre- and post-operatively. However, there is a need to further monitoring of the swallowing problems pre-and post-operatively. Thus, this high rate of swallow and voice problems points to the need to re-evaluate the therapeutic and rehabilitation strategies, the preoperative information given to the patients and to plan future studies to determine quality of life after TL.

Conclusions

- The Swedish version of the SSQ complies with the criteria for content, construct, discriminant and predictive validity and test-retest reliability.
- Cricopharyngeal dysfunction treatment by either laser myotomy or balloon dilatation improved upper oesophageal sphincter opening for at least 6 months.
- HRVM showed that laryngectomees had lower resting pressure at the PES and lower oesophageal peristaltic contraction pressure during swallowing than normal subjects.
- Non-functional TE speakers presented higher phonation pressure at the PES and higher phonation index than functional TE speakers (64 versus 39 mmHg).
- After treatment with BD and/or BT the phonation index PES/oesophagus, phonation and residual pressure values at the PES in non-functional speakers decreased.
- Decreasing phonation pressure from the distal oesophagus to the pharynx was found in functional speakers and non-functional speakers after treatment. These values may indicate that a decreasing pressure along the entire oesophagus up to the PES and pharynx is necessary for a functional TE voice production.
- PES hypertonicity is not the only component in TE speech failure. Fibrosis at the PES and impaired oesophagus motility need to be considered also.
- Swallowing problems were reported by 89 % of the patients after TL and moderate to severe voice handicap was reported by 66%. Most of the subjects who had dysphagia also noted voice problems ($r_s = 0.67$ $p \leq 0.01$).
- After TL, 44% of the patients presented stenosis at the PES. Additional therapeutic interventions to manage problems with voice and/or swallowing after TL were required in 62% of the patients. The most common intervention was BD of the PES.

Appendix

1. Sydney Swallow Questionnaire - English

1. How much difficulty do you have swallowing at present?
2. How much difficulty do you have swallowing THIN liquids? (e.g. tea, juice, beer, coffee)
3. How much difficulty do you have swallowing THICK liquids? (e.g. milkshakes, soups, custard)
4. How much difficulty do you have swallowing SOFT foods? (e.g. mornays, scrambled egg, mashed potato)
5. How much difficulty do you have swallowing HARD foods? (e.g. steak, raw fruit, raw vegetables)
6. How much difficulty do you have swallowing DRY foods (e.g. bread, biscuits, nuts)
7. Do you have any difficulties to swallowing your own saliva?
8. Do you ever have difficulty starting a swallow?
9. Do you ever have a feeling of food getting stuck in the throat when you swallow?
10. Do you ever cough or choke when swallowing SOLID foods? (e.g. bread, meat or fruit)
11. Do you ever cough or choke when swallowing liquids? (e.g. coffee, tea, water, beer)
12. How long does it take to eat an average meal?
13. When you swallow does food or liquid ever go up behind your nose or come out of your nose?
14. Do you ever need to swallow more than once for food go down?
15. Do you ever cough up or spit out food or liquids DURING a meal?
16. How do rate the severity of your swallowing problem today?
17. How much does your swallowing problem interfere with your enjoyment or quality of life?

2. Sydney Swallow Questionnaire- Swedish version

1. Hur stora svårigheter har Du för NÄRVARANDE att kunna svälja?
2. Hur stora svårigheter har Du att kunna svälja TUNNFLYTANDE vätskor? (t ex vatten, te, saft, kaffe)
3. Hur stora svårigheter har Du att kunna svälja TRÖGFLYTANDE vätskor? (t ex fruktsoppor, filmjölk, yoghurt, vaniljsås)
4. Hur stora svårigheter har du att svälja MJUK, SLÄT KOST? (t ex potatismos, äggröra, gröt, purémat)
5. Hur stora svårigheter har du att svälja FAST föda (normal kost)? (t ex kött, frukt, grönsaker, ris)
6. Hur stora svårigheter har du att svälja TORR föda? (t ex bröd, kakor, nötter)
7. Har du några svårigheter att kunna SVÄLJA DIN SALIV?
8. Har du några svårigheter att KOMMA IGÅNG OCH SVÄLJA (påbörja en sväljning)
9. Har du någon gång EN KÄNSLA AV ATT MAT HAKAR UPP SIG (fastnar) i halsen när du sväljer?
10. HOSTAR DU ELLER SÄTTER I HALSEN när du sväljer fast föda? (t ex bröd, kött eller frukt)
11. HOSTAR DU ELLER SÄTTER I HALSEN när du sväljer VÄTSKOR? (t ex kaffe, te, vatten, öl)
12. Hur lång tid tar det för dig ATT ÄTA EN VANLIG MÅLTID?
13. Händer det att mat eller VÄTSKA KOMMER UPP I NÄSAN eller KOMMER UT UR NÄSAN när du sväljer?
14. Behöver du någon gång SVÄLJA MER ÄN EN GÅNG för att födan skall kunna sväljas ner?
15. Händer det någon gång att du HOSTAR UPP ELLER SPOTTAR UT MAT ELLER VÄTSKA UNDER EN MÅLTID?
16. Hur ALLVARLIGA bedömer du att dina SVÄLJNINGSPROBLEM ÄR IDAG?
17. Hur MYCKET påverkar dina sväljningsproblem DIN LIVSGLÄDJE OCH DIN LIVSKVALITÉ?

Voice perceptual assessment after laryngectomy

In order to complete this voice perceptual assessment, you should listen to the patient's voice recording first and then fill in 6 questions. In the first two, you should mark with a circle which level of voice quality and intelligibility you consider more appropriate to what you heard. The other questions include 3 variables which are commonly used for perceptual assessment of all kind of voice patients and voice disorders (hyper functional/tense, breathy, rough) and the fourth variable is commonly used in descriptions of laryngectomees voices. In questions 3 to 6 you should place a "X" in the 100 mm VAS(Visual analogue scale) i.e. if you think the voice is not rough at all you should put the "X" to the left, but if the voice is extremely rough the "X" should be placed to the right.

As a reminder, these are the variable's definitions according to Hammarberg et al.:

Breathy: voice is produced with insufficient glottal closure, vocal folds are vibrating, but somewhat abducted, which creates an audible turbulent noise in the glottis.

Hyper functional/tense: voice sounds strained, due to compression/constriction of vocal folds and larynx tube during phonation with insufficient airflow.

Rough: low-frequency aperiodicity, presumably related to some kind of irregular vocal fold vibration.

Gurgly: wet hoarseness/liquid voice quality.

Please, assess each patient 3 times (completing a new questionnaire each time). Thank you for your time and interest in this project, please do not hesitate to contact Dr Arenaz 71919 or Dr Rydell 71533 if you have any questions.

1. Voice quality

Good

Reasonable

Poor

2. Intelligibility

Good

Reasonable

Poor

3. Rough

4. Breathy

5. Hyperfunctional/tense

6. Gurgly

Populärvetenskaplig sammanfattning

Patienter med dysfagi har svårt att svälja. Dysfagi kan uppträda i alla åldersgrupper, men normalt åldrande kan medföra att det tar längre tid att utföra komplexa rörelser som sväljning. Detta beror bland annat på att antalet muskelfibror och snabba muskelfibrer minskar med stigande ålder. Att samlas kring måltiden och umgås är viktigt för de flesta av oss. Patienter med dysfagi kan därför bli socialt isolerade på grund av att de känner sig obekväma att äta tillsammans med andra. Vanligt förekommande orsaker till dysfagi är medfödda anatomiska avvikelser, tumörer, neurologiska sjukdomar som stroke eller skador orsakade av exempelvis strålbehandling eller kirurgi.

Det faryngoesophageala segmentet (PES), som är placerat mellan svalget och matstrupen, består av muskler från nedre delen av svalget (nedre faryngeala konstriktorn och cricofaryngeus muskeln) och övre delen av matstrupen. En försämrad funktion av PES har stor betydelse för utvecklingen av dysfagi. Hos patienter där struphuvudet avlägsnats (laryngektomi) i samband med canceroperation har PES även en viktig roll för röstproduktionen. För att patienten ska kunna andas gör man ett hål på halsen (trakeostomi). För att återskapa talförmågan sätts en ventil in mellan matstrupen och luftstrupen. Vid utandning kommer luften att via ventilen passera uppåt och får på så sätt slemhinnan i PES att vibrera, varvid ett så kallat trakeoesophagealt tal (TE tal) erhålles. Om PES eller matstrupen av någon anledning inte fungerar kan en lämplig tryckgradient inte upprätthållas och röstbildningen uteblir. Problemen med PES är en utmaning. För att kunna diagnosticera och behandla en sviktande PES fordras ofta ett samarbete mellan flera olika discipliner.

Syftet med avhandlingen är att studera PES funktion och anatomi i samband med dysfagi och röstproduktion efter laryngektomi. För att kunna göra detta har vi använt sväljningsröntgen kombinerat med tryckmätning (videomanometri) av PES och matstrupen och inspelning med höghastighetskamera för att utvärdera PES anatomi och funktion. För att registrera patienternas uppfattning om sväljnings- och röstproblem efter total laryngektomi har vi använt två frågeformulär, nämligen Sydney Swallow Questionnaire (SSQ) och Voice Handicap Index-T (VHI-T). De specifika resultaten av studierna är:

Delarbete I: SSQ har översatts och validerats till svenska förhållanden. Den svenska översättningen har använts till patienter med dysfagi samt friska kontroller, och har visat hög test-retest tillförlitligheten och validitet.

Delarbete II: En del patienter upplever dysfagi på grund av svaghet i muskulaturen i nedre delen av svalget, varvid maten fastnar i ingången till matstrupen (cricopharyngeal dysfunktion). Vi har, hos dessa patienter, studerat effekterna av ballongvidgning och lasermyotomi. För detta ändamål användes videomanometri och SSQ före och efter behandling. Behandling med såväl laser myotomi som ballongvidgning ökade diametern i matstrupsingången under minst 6 månader. Men, vi noterade ingen skillnad mellan de båda metoderna.

Delarbete III och IV: Vi har använt röstbedömningar, höghastighetskamerainspelning och högupplöst videomanometri (HRVM) för att karakterisera PES hos funktionella (delarbete III) och icke funktionella TE talare (delarbete IV). Funktionella TE-talare är de patienter som inte har problem med sväljning eller tal efter insättning av talventil i samband med total laryngektomi och icke funktionella TE talare är de som har problem med dessa funktioner. Det som kännetecknar laryngektomerade i jämförelse med normalpopulationen är ett lågt vilotryck för PES och ett lågt matstrupstryck under sväljning. Vi har även bedömt effekterna av behandling med botulinumtoxin och / eller ballongvidgning av PES hos de patienter som hade röst/sväljningsproblem. Icke-funktionella TE talare, hade före behandling, högre tryck vid PES när de talade (fonationstryck) än funktionella TE talare. Fonationstrycket vid PES minskade hos icke-funktionella TE talare efter behandling. Dessa värden kan tyda på att ett sjunkande tryck längs hela matstrupen upp till PES och svalg är nödvändig för TE röstproduktion.

Delarbete V: Vi undersökte förekomsten av sväljnings- och röstproblem, hos laryngektomerade, recidivfria patienter med hjälp av SSQ och VHI-T. Sväljningsproblem rapporterades hos 89% av patienterna efter total laryngektomi (en förträngning av PES fanns hos 44% av patienterna) och ett måttligt till svårt rösthandikapp hos 66%. Hos 62% av de laryngektomerade patienterna krävdes ytterligare terapeutiska insatser för att hantera röst- och / eller sväljningsproblemen. Därför finns ett tydligt behov av att vidare utreda denna patientgrupps livskvalitet i form av nya studier.

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Paper I



RESEARCH ARTICLE

Open Access

Validation in Swedish of Sydney Swallow Questionnaire

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Abstract

Background: The aim of this study was to translate and adapt the Sydney Swallow Questionnaire to Swedish conditions and to evaluate the validity and test-retest reliability of the Swedish translation in patients with oropharyngeal dysphagia and in healthy controls.

Methods: The validation included 20 patients with swallowing problems and 20 controls matched in age and sex. Patients were assigned a Dysphagia Outcome and Severity Scale. Content, construct, discriminant and predictive validity and test-retest reliability were evaluated.

Results: The Swedish version of the Sydney Swallow Questionnaire was close to the original version, easy to fill in, and well accepted. The form fulfilled the criteria for content, construct, discriminant and predictive validity and test-retest reliability.

Conclusions: The Swedish translation of the Sydney Swallow Questionnaire proved to be a valid instrument to assess dysphagia symptoms and could be used in clinical settings.

Keywords: Oropharyngeal dysphagia, Validation, Questionnaire, Sydney Swallow Questionnaire

Background

Oropharyngeal dysphagia is common in an elderly population. It might be caused by morphological changes such as tumours or inflammation, secondary to neurological diseases or the result of aging. Video-Fluoroscopic Swallow Study (VFSS), videomanometry and flexible endoscopic evaluation of swallowing (FEES) reflect changes in the physiology and biomechanics of swallowing and are valuable tools in determining the extent of dysfunction, but do not take the patient's perspective into account.

Measurements of dysphagia severity are important when making management decisions and in the objective evaluation of treatment efficacy. Combining a self-report instrument with evaluation measures such as VFSS and FEES could contribute to these decisions.

Several questionnaires related to oropharyngeal dysphagia have been translated and validated from their original language (English) to other languages: Swallowing Quality

of Life questionnaire (SWAL-QOL) [1-3] to French [4], Swedish [5], Chinese [6] and Dutch [7,8], Eating Assessment Tool (EAT-10) [9] to Spanish [10] and Italian [11], Dysphagia Handicap Index (DHI) [12] to Portuguese [13] and Arabic [14] and MD Anderson Dysphagia Inventory (MDADI) [15] to Italian [16] and Swedish [17]. EAT-10 has been validated in patients with a wide variety of causes of dysphagia, it is simple to complete and score. DHI is a 25-item questionnaire, in which the patient can assign three responses for each question (never = 0, sometimes = 2, always = 4) resulting in a score between 0 and 100. Moreover, patients rate their dysphagia assigning a score from 0 to 7.

In Sweden there are currently two validated forms that address dysphagia symptoms: MDADI developed to assess dysphagia and quality of life in individuals with head and neck cancer and the SWAL-QOL that consists of 44 items and might be difficult for some patients to complete. We have some experience using the Self-report Symptom Inventory, known as Sydney Swallow Questionnaire (SSQ), see Additional file 1, and this is one of the reasons why we have chosen to validate it [18]. The questionnaire is well accepted, completed in a short time and less time consuming for the clinician in the everyday use, see

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Additional file 2. These are all important aspects to dysphagia patients and to clinicians with limited time.

When translating a form, a cross-cultural adaptation including the examination of cultural and linguistic differences is mandatory in order to obtain an equivalent instrument adapted to Swedish culture [19].

Aim of the study

- To translate and adapt SSQ to Swedish conditions.
- To evaluate the validity and test-retest reliability of the Swedish translation in patients with oropharyngeal dysphagia and in healthy controls.

Methods

Inventory

The SSQ is a self-report inventory with a maximum total score of 1700; a visual analogue scale appears immediately beneath all but one question (Q12). Each visual analogue scale is a horizontal, 100-mm line anchored at each end by extreme statements representing normal function to the left and extreme dysfunction to the right (e.g., does not occur & occurs all the time; no difficulty & extreme difficulty). Participants were instructed to mark a single "X" across the horizontal visual analogue scale at the point which they feel best represented the severity of the particular dysfunction, thus yielding a score of 0–100 for each, corresponding to a distance in millimetres from the origin of the visual analogue scale. In addition, one investigator delivered the written instructions verbally. No attempt was made to guide the patient as to where on the visual analogue scale he/she should make the mark.

The patients answered the SSQ on two occasions: In connection with visits to the Ear Nose and Throat (ENT) clinic or to the Radiology department and at home 3 weeks later. A stamped addressed envelope was given to the subjects for the return of SSQ to the contact person of the study [18].

Those responsible for the study have received formal approval for the translation and validation from the lead author of the SSQ. The translation has been performed by back-translation. The authors separately made a first translation from English to Swedish. In phase two the items with divergent translations were discussed until a consensus was reached. In phase three the SSQ was translated back to English by an independent, native English speaker, graduated in linguistics, who did not participate in the first and second phases. In phase four the SSQ was translated back into Swedish and a pilot group of four patients with swallowing disorders and four healthy subjects completed the questionnaire. In phase five, some of the formulations in the Swedish

version of the questionnaire were altered according to the comments of the pilot group [19].

Participants

The final Swedish version was used, with approval by the ethical committee of the University of Lund (Dnr 2012/464), on 20 subjects without swallowing problems and on 20 patients with swallowing problems, both groups matched in age and sex. Information regarding the study was given to participants to obtain their written informed consent. All were older than 50 years and had adequate cognitive and language skills to comprehend study requirements. The SSQ has been validated in English in a cohort of head and neck patients [20]. None of the participants in our study had undergone previous head and neck surgery nor radiotherapy that might have influenced swallowing function. Controls were recruited when they visited the ENT department and completed the SSQ once.

Patients with oropharyngeal dysphagia for more than 3 months were included after the diagnose was confirmed with VFSS and a clinical evaluation by an otolaryngologist. After inclusion they were assigned a Dysphagia Outcome and Severity Scale (DOSS) score. This is a 7-point scale developed to systematically rate the severity of dysphagia based on VFSS and to make recommendations for diet level, independence level and type of nutrition. Level 7 is normal swallowing and level 1 stands for severe dysphagia [21].

Patients answered the SSQ twice. We included patients with neuromyogenic dysphagia and cricopharyngeal dysfunction (with and without Zenker's diverticulum), this last group was used to measure discriminant validity.

Statistical methods

All data were analyzed using SPSS 22 © Mac version. When a patient omitted more than 3 questions the inventory was excluded from further analysis, if 1 to 3 questions were not answered an estimated score for each omitted question was calculated based on the total score divided by the total possible score for the questions answered. Estimated scores for individual questions were only used for factor-analysis calculations, which requires a complete data set for each patient. We evaluated content, construct, discriminant and predictive validity and test-retest reliability. P values <0.05 (two-tailed) were regarded as significant [22–24].

Content validity

Content validity and internal consistency review whether the relative importance and choice of questions within the inventory are appropriate for the intended use of the SSQ. We chose factor analysis to examine the underlying relationships between the questions and to evaluate

content validity. We have used the principal-components method with the orthotran/varimax rotation. We calculated the Kaiser-Meyer-Olkin as a measure of sampling adequacy and Bartlett's test of sphericity (if statistically significant it indicates that the relationships among the coefficients are not random). The factor analysis output presented a matrix of factor loadings. It is generally accepted that a factor loading greater than 0.3 is significant, but we selected 0.6 as cut-off for an individual question in the SSQ to be considered as part of a particular factor and it must not be represented in any other factor [18,24]. Factor analysis provides a communality summary that gives a measure of the variance of each question that can be accounted for the combination of all the factors, which overall should account at least for 75% of the total variance of the questionnaire. The total variance that each question contributes should be more than 0.6 [18,24].

Construct, discriminant and predictive validity

Construct validity refers to whether an instrument measures the true clinical state of the patient. We hypothesized that the DOSS correlated with the SSQ and used Spearman's nonparametric correlations to confirm this.

Discriminant validity measures the SSQ ability to distinguish clinically significant differences in therapeutic responses over time, e.g. pre and postoperative scores.

We compared the SSQ score, using the Wilcoxon test, pre-operatively and 4 week post-operatively in 4 patients with Zenker's diverticulum treated with staples myotomy and 6 with cricopharyngeal dysfunction treated with balloon dilatation.

Predictive validity or known-groups validity refers in this case to whether SSQ can differentiate between patients with dysphagia and normal swallowers or patients with different severity of dysphagia. We have used the Mann Whitney U test to evaluate predictive validity.

Test-retest reliability

The test-retest reliability measures the ability of the SSQ to yield consistent scores over time, given that the clinical status of the patient remains stable. We evaluated the variability of the score within 3 weeks time using the Intraclass Correlation Coefficient (ICC) and limits of agreement (LOA), which is the 95% confidence intervals of the mean of the individual differences between test and retest [22].

Ceiling and floor effects were assessed. A ceiling effect is said to occur when a high proportion of subjects in a study have maximum scores on the observed variable (the opposite is called floor effect). This makes discrimination among subjects on the top or the lower end of the scale impossible [25].

Results

Descriptive statistics

We recruited 20 controls and 20 patients with dysphagia, 10 men and 10 women, mean age 72 years in both groups. All responded the SSQ in less than 10 min. One patient did not answer one question and one patient did not submit the postoperative questionnaire. None of the participants experienced difficulties in completing the questionnaire.

Content validity (internal consistency)

Kaiser-Meyer-Elkin was 0.75 indicating a sufficient sample size for the number of questions in the questionnaire. Bartlett's test of sphericity was significant $p < 0.001$.

The factor analysis matrix, showed that all questions except Q12 contributed significantly to factor 1 (Table 1). Question 12 (related to how long time does it take to eat) was the sole contributor to factor 3. All questions had a communality loading > 0.6 and 85% of the variance in response is explained by the 4 major factors identified by the analysis, 61% for the first factor (dysphagia).

Construct, discriminant and predictive validity

Spearman correlations coefficient was -0.70 , $p < 0.001$ confirming construct validity (Figure 1).

Regarding discriminant validity the preoperative mean value was 722, median 634 and postoperative mean 313, median 234 and the Wilcoxon signed ranks test was significant with $p = 0.002$ (Figure 2).

Predictive validity: as hypothesized, dysphagic patients scored significantly higher on SSQ, $p < 0.001$. The mean score for controls was 51, median 48; minimum score was 5 and maximal 102. The mean score for patients was 638, median 607; minimum score was 113 and maximal 1489 (Figure 3).

Test-retest reliability

The ICC for patient scores within 3 weeks was 0.98, 95% CI (0.96-0.99) significant $p < 0.001$ (Table 2), 5 questions had ICC < 0.7 : Q1 0.63, Q3 0.64, Q8 0.53 and Q12 0.61.

Discussion

A self-report instrument is commonly used to assess patient reported outcome, it guarantees that questions are asked in a standardized manner, and facilitates comparisons within and between groups. These inventories are designed to measure either health-related quality of life (HRQoL) or functional health status (FHS), HRQoL refers to the perception individuals may have on their health taking into account social, functional and psychological issues, whereas FHS quantifies the symptomatic severity of a disease (in this case dysphagia) on particular functional aspects. DHI, MDADI and SWAL-QOL are HRQoL questionnaires, EAT-10 and SSQ are

Table 1 Summary of the factor analysis matrix with communality summary in patients, n = 20

Question	Factor 1 dysphagia	Factor 2	Factor 3	Factor 4	Communality summary loading
1	0.788	0.388	0.239	-0.106	0.840
2	0.837	-0.345	-0.184	-0.153	0.877
3	0.809	-0.362	0.066	-0.312	0.887
4	0.889	-0.248	0.189	-0.079	0.893
5	0.805	0.176	0.424	-0.249	0.922
6	0.786	0.343	0.196	-0.282	0.852
7	0.622	0.455	-0.498	0.170	0.871
8	0.625	0.498	0.120	0.418	0.827
9	0.765	0.124	-0.003	-0.258	0.667
10	0.781	0.099	0.000	0.449	0.821
11	0.858	-0.293	-0.225	0.243	0.932
12	0.336	-0.287	0.759	0.346	0.891
13	0.812	-0.452	-0.036	0.251	0.928
14	0.853	0.030	-0.227	0.067	0.785
15	0.822	-0.322	-0.310	-0.012	0.876
16	0.914	0.175	0.039	0.050	0.871
17	0.804	0.140	-0.166	-0.230	0.747
Variance	61.2	9.5	8.3	6.2	

FHS questionnaires. For optimal use of both types of inventories, it is necessary to combine psychometric and utility approaches [26-28].

The Swedish version of SSQ was well accepted, the response rate was high, and the number of missing items was very low (only Q6 in patient 19). The results indicated that the translation of SSQ was easy to manage and close to the original. It took less time to answer (less than 10 minutes) and score (less than

4 minutes), compared to SWAL-QOL and the MDADI. It had good test-retest reliability. The ICC for the total score was 0.98. All the questions reached the level 0.7 except Q1 (grade of dysphagia), Q3 (difficulty to swallow thick liquids), Q8 (difficulty to initiate the swallowing) and Q12 (how long does it take to eat), (Table 2).

Our sample was small which might be a limitation in our study, but the Kaiser-Meyer-Olkin was 0.75, indicating

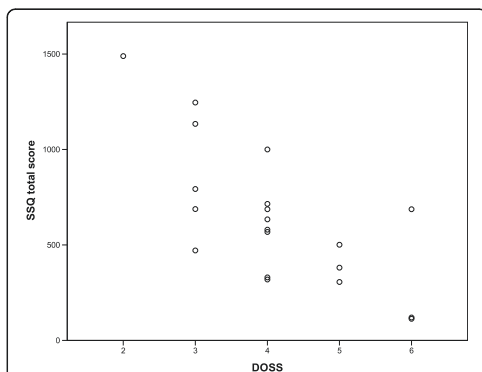


Figure 1 Construct validity; Spearman's correlation between DOSS and the SSQ total score.

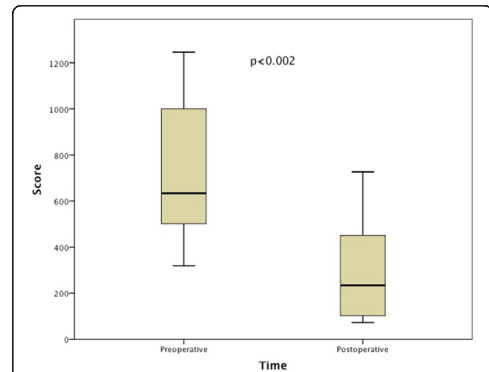
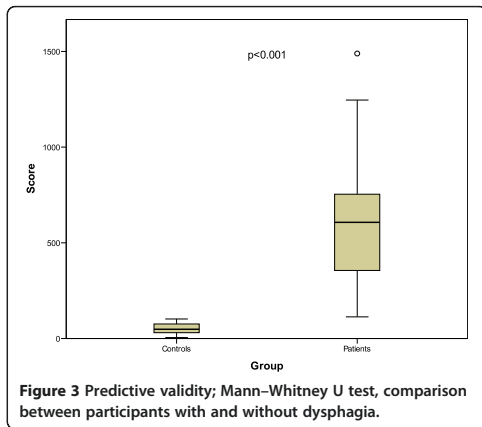


Figure 2 Discriminant validity; Wilcoxon signed rank test, showing pre-operative and 1 month post-operative comparison.



a sufficient sample for the number of questions in our questionnaire. The Swedish SSQ satisfied as well criteria for content, construct, discriminant, and predictive validity. Regarding content validity four factors accounted for 85% of its variance, the dominant factor (dysphagia) accounted for 61%, slightly better than in the original article that was 59%.

Table 2 Summary of the test–retest reliability, using the Intra-class Correlation Coefficient (ICC), confidence interval (CI)

	ICC	95% CI	P-value
Total score	0.98	0.95-0.99	< 0.001
Q1	0.63	0.27-0.83	0.001
Q2	0.86	0.28-0.84	< 0.001
Q3	0.64	0.29-0.84	0.001
Q4	0.94	0.85-0.97	<0.001
Q5	0.88	0.72-0.95	<0.001
Q6	0.93	0.82-0.97	<0.001
Q7	0.85	0.65-0.94	<0.001
Q8	0.53	0.12-0.78	0.007
Q9	0.74	0.45-0.89	<0.001
Q10	0.87	0.71-0.95	<0.001
Q11	0.76	0.50-0.89	<0.001
Q12	0.62	0.25-0.83	0.002
Q13	0.91	0.79-0.96	<0.001
Q14	0.80	0.57-0.92	<0.001
Q15	0.93	0.83-0.97	<0.001
Q16	0.75	0.47-0.89	<0.001
Q17	0.81	0.58-0.92	0.001

The total inventory score showed a -0.70 correlation with the DOSS, showing excellent construct validity. The correlation is negative: DOSS score decreases (level 1) and SSQ score increases (maximum 1700) when dysphagia severity rises. Wallace et al. calculated the construct validity correlated the SSQ with a global assessment score obtaining a positive linear correlation 0.69 [18].

Discriminant validity is important for using the inventory to measure responses to treatment and to establish the efficacy of that treatment. The mean preoperative total score decreased by an average of 60% postoperatively, 10% less than in the original article, but our study includes patients treated both with myotomy and balloon dilations and they probably differ in their postoperative results.

Subjects with dysphagia had significantly higher scores than the age- and gender-matched control group, suggesting very good predictive validity that helps to distinguish between individuals with/without dysphagia, which is central in a broader use. The cut-off score for dysphagia in our version of SSQ is 111, this is the controls mean total score plus two standard deviations ($51 + (2 \times 30) \geq 111$). Score values higher than 111 should be considered as pathological in our validation. However, in Wallace et al. SSQ the cut-off score is 193 for 19 controls with a mean age of 62.

Floor and ceiling effects were not found in the Swedish SSQ. They were not reported in the SSQ original version.

By performing a Swedish version and validation of SSQ we have obtained a useful tool to record patient reported outcome of swallowing problems. This self-report instrument is not only easy for the patients to use, but also very efficient for the clinician.

Conclusions

The Swedish version of the SSQ seems to be a reliable and consistent instrument for the assessment of subjective dysphagia symptoms. The availability of validated patient reported outcome instruments such as the SSQ might be an important contribution to both research and screening of dysphagia in Sweden.

Additional files

Additional file 1: Original Sydney Swallow Questionnaire.
Additional file 2: Swedish version of the Sydney Swallow Questionnaire.

Abbreviations

CI: Confidence intervals; DHI: Dysphagia Handicap Index; DOSS: Dysphagia Outcome and Severity Scale; EAT-10: Eating Assessment Tool; ENT: Ear Nose and Throat; FEES: Flexible Endoscopic Evaluation of Swallowing; FHS: Functional Health Status; HRQoL: Health-Related Quality of Life; ICC: Intra-class Correlation Coefficient; MDADI: MD Anderson Dysphagia Inventory; SWAL-QOL: Swallowing Quality of Life Questionnaire; SSQ: Sydney Swallow Questionnaire; VFSS: Video-Fluoroscopic Swallow Study; Q: Question.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

BA and MB conceived of the study, participated in its design and coordination, collection of data and drafted the manuscript. BA performed the statistical analysis and interpretation of data. All authors have read and approved the final manuscript.

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Paper II



RESEARCH ARTICLE

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Treatment of cricopharyngeal dysfunction: a comparative pilot study

Beatriz Arenaz Búa^{1,2*}, Rolf Olsson³, Ulla Westin², Roland Rydell^{4,5} and Olle Ekberg⁶

Abstract

Background: Cricopharyngeal dysfunction is a narrowing at the level of the upper oesophageal sphincter caused by failed or incomplete sphincter opening as a result of lack of pharyngoesophageal coordination or reduction in the muscular compliance of the upper oesophageal sphincter. Oropharyngeal dysphagia is a typical symptom. Videomanometry allows direct comparison of pressure readings with dynamic anatomy during swallowing.

Methods: This is a prospective randomized pilot study that compares the effect of balloon dilatation and laser myotomy in cricopharyngeal dysfunction. We used videomanometry as an objective measure and the Swedish version of Sydney Swallowing Questionnaire as patient's self-assessment at baseline and 1 and 6 months after treatment.

Results: The UES sagittal diameter increased from 5.6 mm pre-operatively to 8.4 mm 6 months post-operatively with no differences between treatment groups. Preoperative mean Sydney Swallowing Questionnaire score was 770 and 6 months post-operative score 559, with no difference between the treatments in our cohort.

Conclusion: Cricopharyngeal dysfunction treatment by either laser myotomy or balloon dilatation improved upper oesophageal sphincter opening during at least 6 months.

Trial registration: ISRCTN84905610, date: 081214

Keywords: Cricopharyngeal dysfunction, Upper oesophageal sphincter, Cricopharyngeus muscle, Videomanometry, Sydney Swallowing Questionnaire

Background

The pharyngoesophageal segment (PES) is made up of the inferior pharyngeal constrictor, the cricopharyngeus muscle (CPM) and the proximal part of the cervical oesophagus. The upper oesophageal sphincter (UES) is a 2.5–4.5 cm high-pressure zone visualized on manometry between the pharynx and oesophagus. PES refers to anatomy and UES to function, but the terms are synonymous. The CPM is 1–2 cm and it is a key component of the UES because it is the only portion that actively participates in all reflexive relaxation and tightening activities [1]. Cricopharyngeal dysfunction (CPD),

characterized by oropharyngeal dysphagia, may be due to incoordination as well as reduction in maximal opening of the UES during transphincteric flow [2, 3].

Radiological assessment of CPD can be challenging [3]. Videomanometry (VM) combining solid state manometry and videofluoroscopy allows direct comparison of pressure readings with dynamic anatomy giving a better appreciation of how these readings are related to the passage of the bolus [4, 5].

The CPM is frequently targeted for intervention in CPD [6]. There are four approaches to the CPM, including: the external technique, which is indicated when a biopsy is needed; the endoscopic approach, which offers the choice of laser or the surgical stapler; bougie or balloon dilatation of the UES and botulinum toxin injection in the CPM endoscopically [7] or percutaneous [8]. In our department we use balloon dilatation and laser myotomy to treat CPD without Zenker diverticulum.

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Aim of the study

This is a randomized and prospective pilot study to compare the effects of balloon catheter dilatation (BD) and laser myotomy (LM) in CPD.

Methods

We included patients who had dysphagia due to CPD without Zenker diverticulum for more than 3 months and who had not undergone any previous interventions in the PES. They underwent clinical assessment by an otorhinolaryngologist. None of the patients had medical instability, cervical osteophytes, neurological diseases, untreated reflux or hepatitis. All were informed about the benefits and risk of the procedures and signed an informed consent. After the CPD was confirmed by VM, they were randomized to LM or BD. The study was approved by the ethical committee of the University of Lund.

We evaluated the variables pre- and 1 and 6 months post-treatment using VM and the Swedish version of the Sydney Swallowing Questionnaire (SSQ) [9], a reliable and consistent instrument for the assessment of subjective dysphagia symptoms. The SSQ is a self-report inventory with a maximum possible total score of 1,700; it consists of 17 questions yielding a score of 0–100 for each.

Videomanometry was performed in frontal and lateral projection with the patient seated. Videofluoroscopy was done before inserting the manometry catheter, in order to measure the dimensions of the PES. Then a small amount of topic anaesthetic (Xylocain 2%; Astra Zeneca, Södertälje, Sweden) was placed in the nostril. The catheter was introduced through the nose to UES and oesophagus under fluoroscopic guidance in order to reduce patient discomfort. Time for examination was less than 10 min and total fluoroscopy within 100 s, radiation dose 0.3 mSv. All participants were instructed to swallow 10 ml of water-soluble contrast (Barium contrast medium, 240 mg/ml, Nycomed Imaging, Oslo, Norway) three times. Retention and penetration of the contrast as well as 20 variables were analysed by VM (Table 1).

The catheter's diameter was 4.6 mm with four solid-state pressure transducers positioned 2 cm apart (Konigsberg Instruments Inc. Pasadena, CA, USA). The proximal sensors were dorsal oriented to measure 120°, while the two distal transducers were circumferential, allowing 360° measurements. All sensors were radiopaque and easy to identify during fluoroscopy. The sampling frequency was 64 Hz. The analogue signal was converted to a digital signal (Polygraf, SynMed Medicinteknik, Spånga; Sweden). The pressure values were registered in mmHg and referred to atmospheric pressure. The system was calibrated at 0 and 50 mmHg and carried out at 37°C [10].

Table 1 Videomanometry variables, all of them in sagittal projection except 1–3

	Preop	Post1	Post2	P value	P-value treat
Frontal UES diam.by CPM	9.9	10.6	10.0	0.68	0.78
Frontal UES diam.15 mm over CPM	20.5	20.7	18.7	0.49	0.63
Frontal UES diam.15 mm under CPM	12.0	12.1	13.1	0.21	0.03
UES diam.by the CPM	5.6	7.6	8.4	0.008	0.86
UES diam.15 mm over CPM	13.3	15.2	16.7	0.05	0.29
UES diam.15 mm under CPM	9.6	9.9	11.5	0.16	0.39
Maximal hyoid movement 1	10.9	10.2	11.0	0.77	0.32
Maximal hyoid movement 2	12.5	14.5	16.3	0.11	0.28
Maximal hyoid movement 3	16.5	17.5	18.2	0.67	0.20
Maximal laryngeal elevation	21.4	22.7	24.5	0.61	0.36
Resting UES pressure	65.0	54.4	56.0	0.60	0.92
Residual pressure UES relax dry	3.0	1.3	2.5	0.42	0.54
Residual pressure UES relax wet	3.0	1.3	4.6	0.80	0.73
Duration of UES relax dry	0.5	0.5	0.5	0.68	0.85
Duration of UES relax wet	0.7	0.6	0.7	0.50	0.50
UES contraction pressure	280.0	275.0	293.0	0.95	0.60
Intrabolus pressure	49.0	34.0	–	–	–
Pharyngeal pressure	292.0	302.6	184.0	0.13	0.37
Tongue base pressure	261.0	241.0	187.0	0.02	0.63
Oesophagus amplitude	77.0	82.0	83.0	0.53	0.09

Diameter is measured in mm and pressure in mm Hg. P-value = within subjects, P-value treat = difference between treatments. Maximal hyoid movement is hyoid's elevation (=maximal hyoid movement 1) followed by a ventral movement (=maximal hyoid movement 2). The diagonal line between the resting position and maximal craniocervical movement is the maximal hyoid movement 3.

CPM cricopharyngeus muscle, Preop pre-operatively, Post1 1 month post-operatively, Post2 6 months post-operatively, UES upper oesophageal sphincter.

Follow-up was made in an outpatient clinic 1 and 6 months after treatment.

Flexible oesophagoscopy was conducted in all patients with reflux symptoms and they received proton pump inhibitors during 2 months preoperatively [11]. Myotomy, using CO₂ laser, was performed under general anaesthesia, according to the technique described by Lawson [12]. We used neither fibrin glue to the incision nor nasogastric feeding tube to avoid interference with the healing process of the surgical field. During the first postoperative 2 days the patients were fed parenterally. On day 3 a liquid and semisolid diet was authorized and the patient discharged. On day 10 normal diet was resumed. Preoperative temperature, C-reactive protein (CRP), erythrocyte sedimentation rate (SR) and leucocytes were taken and the same procedure was performed 4 h after the operation and in the morning on days 2 and 3 after surgery.

Dilatation was performed with a controlled radial expansion balloon with diameter 18–20 mm, during 2.5 min under general anaesthesia. Temperature and blood test including CRP, SR and leucocytes were taken preoperatively and 4 h postoperatively and in the morning on day 2. If these parameters were normal a liquid and semisolid diet was authorized and the patient discharged. On days 5 to 7 normal diet was resumed.

Statistics

Data were processed with SPSS version 22 for Mac and statistical analysis was made using descriptive statistics and repeated measures ANOVA, p values <0.05(two-tailed) were regarded as significant.

Results

Ten patients were included in the study, but only eight patients completed. The mean age was 74 years and the age range 67–81 years. Four participants were male and four female. After being randomized four were treated with BD and four with LM. No complications were reported.

The follow-up time was 1 and 6-months postoperative with SSQ, VM and clinical control in the outpatient clinic.

SSQ

The response rate to SSQ was 100%. Mean SSQ score (Table 2) was pre-operative: 770 (CI 457–1,084) BD: 691, LM: 850, 1 month post-operative: 340 (CI 74–606) BD: 398, LM: 281 and 6 months post-operative: 559 (CI 212–906) BD: 718, LM: 399 indicating a statistical significant improvement (p = 0.003) in self-reported swallowing impairment, but we could not find a significant difference between the different treatments in our cohort (p = 0.72).

Table 2 Pre- and post-treatment Sydney Swallowing Questionnaire’s mean total score presented by case and treatment

Case	Treatment	SSQpreop	SSQpost1	SSQpost2
1	BD	1,142	704	960
2	LM	1,131	756	744
3	BD	648	121	968
4	BD	240	78	86
5	BD	734	691	860
6	LM	1,217	235	736
7	LM	305	24	70
8	LM	748	111	48

BD balloon dilatation, LM laser myotomy, SSQ Sydney Swallowing Questionnaire, preop pre-operatively, post1 1 month post-operatively, post2 6 months post-operatively.

Highest pre-operative mean scores (50 or more) were registered in seven questions: difficulty in swallowing solid food (question 5), difficulty in swallowing dry food (question 6), food gets stuck in the throat (question 9), choke with solid food (question 10), swallowing more than once (question 14), dysphagia severity rate (question 16) and quality of life (question 17). Post-operative mean scores decreased in all these questions, with values equal to 45 or less (Table 3).

Videomanometry

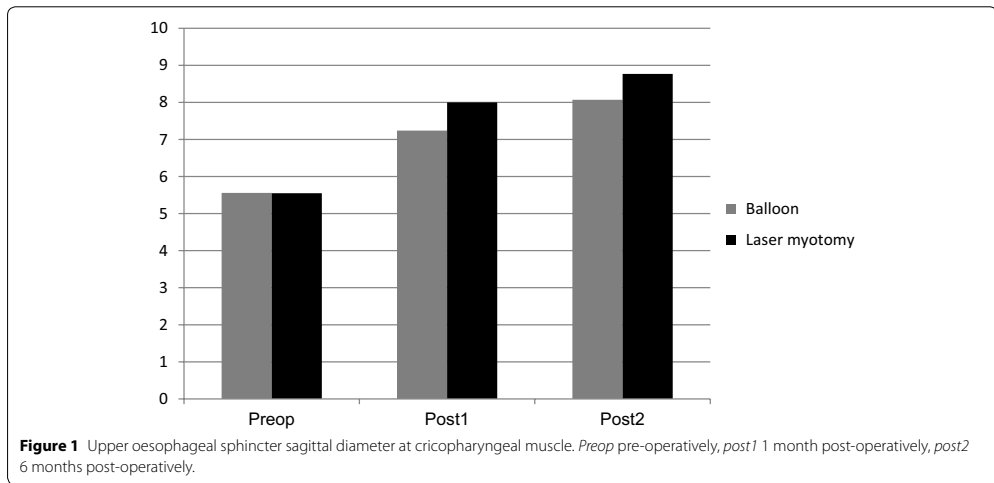
The UES sagittal diameter at the CPM increased if we considered both treatments, (p = 0.008): pre-operatively mean 5.6 mm (CI 4.1–6.9), BD: 5.6 mm, LM: 5.6 mm, 1 month post-operatively mean 7.6 mm (CI 6.5–8.7), BD: 7.2 mm, LM: 8 mm and 6 months post-operatively mean 8.4 mm (CI 6.4–10.4), BD: 8.1 mm, LM: 8,7 mm, Figure 1, but we could not find a significant difference between the two treatments in our cohort (p = 0.86).

Tongue base pressure decreased (p = 0.02) from pre-operatively: 261 mm Hg (CI 75.3–475) BD: 269 mm Hg, LM: 250 mm Hg, 1 month post-operatively: 241 mm Hg (CI 65.2–432.7) BD: 236 mm Hg, LM: 249 mm Hg, to 6 months post-operatively: 187 (CI 37.7–358.2) BD: 178 mm Hg, LM: 200 mm Hg, without a difference between the treatments in our cohort (p = 0.63).

Table 3 Pre- and post-treatment Sydney Swallowing Questionnaire’s mean scores by question

SSQ Score	Preop	Post1	Post2
1. Swallowing difficulty	36	17	40
2. Thin liquids	32	20	31
3. Thick liquids	26	20	34
4. Soft food	38	19	23
5. Hard food	64	18	42
6. Dry food	61	30	45
7. Swallowing saliva	23	12	17
8. Starting a swallow	47	17	34
9. Food stuck in the throat	65	28	45
10. Cough/choke with solids	60	22	40
11. Cough/choke with liquids	35	19	26
12. Time to eat a meal	33	28	30
13. Food/liquid behind nose	25	12	16
14. Swallow more than once	58	26	40
15. Cough/spit during a meal	44	20	28
16. Dysphagia severity rate	60	21	43
17. Quality of life	68	16	38
Total	770	340	559

SSQ Sydney Swallowing Questionnaire, preop pre-operatively total score, post1 1 month post-operatively total score, post2 6 months post-operatively total score.



The pre-operative intrabolus pressure mean value, at the level of the inferior pharyngeal constrictor, was 30 mmHg, because of technical reasons it could not be measured after 6 months in the last four patients and could therefore not be analysed.

Three patients (number 2, 5 and 8) had pre-operative subepiglottic penetration of the contrast in the VM, but none of them had it post-operatively. Three (number 3, 5 and 6) had retention of the contrast in the vallecula pre- and postoperatively. The pre-operative oesophagus amplitude mean was 77 mm Hg, 1-month post-operatively it was 82-mmHg and 6 months post-operatively 83 mmHg.

The following variables did not change post-operatively: Frontal and sagittal diameter of UES, 15 mm over and under the CPM, pharyngeal pressure at the level of the constrictor inferior muscle, maximal hyoid movement, laryngeal elevation, resting UES pressure, residual pressure during UES relaxation dry and wet, duration of UES relaxation dry and wet and UES contraction pressure (Table 1).

Discussion

Most published studies on CPD treatment are small and retrospective, without randomization and/or control and a short follow-up. Our study is prospective and randomised but with a limited sample size, thus the results should be interpreted with caution.

A postoperative improvement was seen for the SSQ score, UES sagittal diameter at CPM and tongue base pressure after BD and LM. Although we could not find a difference between the treatments in our cohort, patients

1, 3 and 5 treated with BD had high 6 month-post SSQ scores, patients 3 and 5 had increased UES diameter at CPM only 0, 7 mm (Table 4) and these three participants had oropharyngeal dysphagia, made a new VM and required retreatment after 12 months: one with LM and two with new BD. None of the patients who underwent LM have been treated again.

The success rate of BD varies from 35 to 85% [13]. Considering SSQ and the UES sagittal diameter, the success rate for BD in our study was 100% after 1 month, but only 50% after 6 months.

Balloon catheter dilatation protocols are not yet standardized across institutions [14, 15]. The diameter and

Table 4 Pre- and post-treatment UES sagittal diameter at cricopharyngeal muscle

CASE	Treatment	UES preop	UES post1	UES post2	UES post2-UES preop
1	BD	4.7	7.3	7.0	2.3
2	LM	8.3	9.5	10.0	1.7
3	BD	8.3	7.7	9.0	0.7
4	BD	4.7	7.7	11.0	6.3
5	BD	4.6	6.3	5.3	0.7
6	LM	5.3	5.6	6.5	1.2
7	LM	3.3	8.3	6.6	3.3
8	LM	5.3	8.6	12.0	6.7

Measures are made in mm, during bolus passage in videofluoroscopy.

BD balloon dilatation, LM laser myotomy, UES upper oesophageal sphincter, *preop* pre-operatively, *post1* 1 month post-operatively, *post2* 6 months post-operatively.

pressure of the balloon and the duration of each dilatation varies and appears to be dependent upon the personal preference and the experience of the operator. The UES is kidney shaped which might explain why the dilatation with a cylindrical device only treats part of the sphincter effectively and why it is possible to introduce a 4.6 mm catheter when the sagittal diameter at CPM is only 3.3 mm [16–18, 19]. Cates et al. propose in their study that the circular model underestimates UES area by 60%. The largest dilator currently available for UES dilation is 20 mm. Belafsky et al. in a recent study show how the efficacy of the BD improves using two cylindrical catheters instead of one and they propose a kidney shaped oesophageal dilator [17].

The success rate of myotomy by external approach or by endoscope is around 70% which is in accordance with our results [20]. The ability to recognize the buccopharyngeal fascia, the visceral layer of the middle layer of the deep cervical fascia with the endoscopic technique [21], explains the low rate of complications. We restrict the external approach to cases in which appropriate exposure is impossible to reach via the endoscopic approach.

After an initial compensatory increase of tongue base, intrabolus and pharyngeal pressure at the inferior constrictor, the pharynx becomes progressively dilated and weak proximal to the obstruction as the severity of CPD increases [10]. Frontal and sagittal diameter of UES 15 mm over and under the CPM, pharyngeal pressure at the level of constrictor inferior muscle, maximal hyoid movement, laryngeal elevation, resting UES pressure, residual pressure during UES relaxation dry and wet, duration of UES relaxation dry and wet, UES contraction pressure, did not show any post-operative changes in our cohort (Table 1). These data suggest that once the diagnosis is made, if the comorbidity and functional status of the patient allows the intervention, it should be done before the pharyngeal weakness is irreversible. The length of time over which this may occur is still unknown and is in an area of continuing research [22].

In order to analyse pre- and post-operative changes in UES, we should measure cross sectional dimensions as well, which is not feasible by VM. High-resolution manometry combining oesophageal and pharyngeal impedance and ph-monitoring improves the diagnosis accuracy in the PES and future studies should use these techniques.

Conclusion

According to measures with both VM and SSO, LM improves UES opening in 100% and BD in 50% of the patients in our study during at least 6 months. Earlier CPD treatment might relieve symptoms before pharyngeal dimensions change and help to prevent irreversible pharyngeal dilatation and weakness. The success of the procedure is strongly related to the selection of patients.

Abbreviations

BD: balloon catheter dilatation; CPD: cricopharyngeal dysfunction; CI: confidence interval; CPM: cricopharyngeus muscle; CRP: C-reactive protein; SR: erythrocyte sedimentation rate; LM: laser myotomy; PES: pharyngo-oesophageal segment; UES: upper oesophageal sphincter; VM: videomanometry.

Authors' contributions

BA, UW, RR, RO and OE conceived of the study, participated in its design and coordination, BA, RO collected the data and BA, UW, RR, RO and OE drafted the manuscript. BA and RO performed the statistical analysis and interpretation of data. All authors read and approved the final manuscript.

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Compliance with ethical guidelines

Competing interests

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Paper III



The Pharyngoesophageal Segment After Total Laryngectomy

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Abstract

Objective: The aim of the present study was to characterize the pharyngoesophageal segment in laryngectomees who rated themselves as functional tracheoesophageal speakers.

Methods: Voice perceptual assessment, high-resolution videomanometry of swallowing and phonation, and high-speed camera recording during phonation provided information about the anatomy and function of the pharyngoesophageal segment.

Results: Fourteen patients were included in the study. The voice assessments presented high intra/inter-listener reliability. We found a significant correlation between roughness and poor voice quality, hyperfunction and poor intelligibility, and poor voice quality, long time since the operation, and old age. High-resolution videomanometry during phonation revealed decreasing mean pressures from the distal esophagus to the pharynx and confirmed low resting pressures at the pharyngoesophageal segment and low esophageal peristaltic contraction pressures after laryngectomy in comparison to normal subjects. The neoglottis shape was mainly circular and presented a strong mucosal wave in most of the patients on the high-speed camera recording.

Conclusions: Perceptual voice assessment and high-speed camera recordings provided baseline information about voice characteristics and vibration regularity of the neoglottis. Additionally, the quantitative measures obtained with high-resolution videomanometry may have clinical applicability as reference data in voice rehabilitation after total laryngectomy.

Keywords

high-resolution videomanometry (HRVM), high-speed camera (HSC), pharyngoesophageal segment (PES), total laryngectomy (TL), tracheoesophageal voice prosthesis (TEVP)

Introduction

Early stage laryngeal cancer can be treated with radiotherapy or laser surgery. In large tumours or in case of recurrence of the disease, a total laryngectomy (TL) may be necessary. In most cases, a puncture between the trachea and the esophagus is made in the same session as the TL to provide patients with tracheoesophageal (TE) speech. A tracheoesophageal voice prosthesis (TEVP) is placed in the TE fistula. When the laryngectomee covers his stoma, air from the lungs is shunted through the TEVP in the esophagus and into the neoglottis for voice production. Prior to the introduction of the TE speech, the most common speaking techniques for laryngectomees were esophageal (E) speech or the use of an electrolarynx.¹

The main difference between TE and E speech is the way by which the air enters into the esophagus and the amount of air the speaker can use. A TE speaker uses air from the lungs, and the speech is produced on exhalation as in laryngeal speech. In E speech, only a small volume of air is used since

the upper part of the esophagus serves as an air reservoir.² A feature shared by TE and E speech is the voice source: the neoglottis or pharyngoesophageal segment (PES), which mainly consists of the cricopharyngeal muscle, closely associated with the proximal esophagus, the inferior pharyngeal constrictor muscle, and its lining mucosa.³

After total laryngectomy, the interruption of the upper respiratory tract, the trauma to the surrounding nerves, and the myotomy of the cricopharyngeal muscle alters not only the high-pressure zone of the PES¹ but also the esophageal

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peristalsis.⁴⁻⁶ The success of TE speech is related to the morphodynamic of the PES.⁵

To assess the morphology and physiology of the PES, different methods can be used; we have chosen 3 of them: voice perceptual analysis, high-speed camera (HSC) recording, and high-resolution videomanometry (HRVM). Perceptual analysis of TE voice is an important outcome measure in the voice rehabilitation after TL. However, the use of the GRBAS scale (G = grade of hoarseness, R = roughness, B = breathiness, A = asthenicity, S = strainness) on laryngectomees appears to be suboptimal^{7,8} due to the differences between laryngeal and TE voice. There is a variety of voice perceptual rating scales for TE voice^{2,9}: Moerman et al⁷ proposed the INFVo (impression, intelligibility, noise, fluency, and voicing) rating scale. Hurren et al⁸ developed the Sunderland tracheoesophageal voice perceptual scale with focus on the “overall grade” of voice quality and “neoglottal tonicity.” Regardless the rating scales for perceptual assessment, one of the most important issues in the use of this evaluation method is the intra- and interrater reliability.⁸

A flexible or rigid laryngoscope connected to an HSC obtains images of the vibrating neoglottis from above and analyzes periodic as well as aperiodic vibrations by performing recordings with a high number of frames per second (≥ 2000).^{2,10} A new tool to evaluate the PES in TE speakers is HRVM, which consists of videofluoroscopic examination combined with high-resolution manometry. The catheter contains pressure sensors that are 1 cm apart, circumferentially sensitive, not affected by the axial asymmetry in the pharynx, and captures pressures from the pharynx to the esophagus.¹¹ Normal pressure of the PES during phonation and the possibility to vary the pressure is believed to be relevant for a successful TE speech. The HRVM allows accurate and simple recording of pressure at PES and esophagus. This might provide valuable information for management of TE speech failure.

Aims of the Study

- To use voice perceptual assessment to characterize functional TE speakers. Hypothesis: Functional TE speakers have good voice quality and intelligibility.
- To measure HRVM variables in swallowing and phonation. Hypothesis: Functional TE speakers present low phonation pressure at PES.
- To study the anatomy and mucosal vibration of the PES with HSC. Hypothesis: Functional TE speakers present specific features such as good visibility of the neoglottis, strong mucosal wave, and small amount of saliva.
- To characterize the anatomy and function of the PES, which might be clinically relevant in the rehabilitation of voice and swallowing after TL.

Table 1. Patients' Data on Staging, Radiotherapy, and Postoperative Time in Years.

Patient	Radiotherapy	TNM	Time Postoperative
1	Preoperative	rT3N0M0	3
2	Preoperative	rT2N0M0	0.4
3	Postoperative	T4N0M0	6
4	Preoperative	rT3N0M0	0.5
5	Preoperative	rT4N0M0	17
6	Preoperative	rT3N0M0	15
7	NO	T4N0M0	17
8	NO	T4N0M0	20
9	Preoperative	rT3N2cM0	7
10	Preoperative	rT2N0M0	20
11	Preoperative	rT1cN0M0	0.8
12	Preoperative	rT3N0M0	0.5
13	Preoperative	rT1bN0M0	3
14	Preoperative	rT2N1M0	4

Material and Methods

Fourteen TE functional speakers without swallowing complaints were recruited. They rated themselves as having good or reasonable speech quality, good intelligibility on the telephone, and no need for treatment. There were 12 men and 2 women, all former smokers, mean age 70.7 years (range, 49-85 years). Mean time after surgery was 8 years (range, 0.4-20 years), median 5 years. All were diagnosed with squamous cell carcinoma, except 1 that had a chondrosarcoma.

Eleven patients had received radiotherapy preoperatively, 1 received it postoperatively, and 2 were not treated with radiotherapy (see Table 1). Cricopharyngeal myotomy had been performed in the same session as the laryngectomy. They finished their treatment at least 3 months before being included in the study and presented no evidence of recurrent disease. Their stoma was covered with a heat and moisture exchanger valve. All patients signed informed consent and underwent clinical evaluation by an otolaryngologist. The study was approved by the local ethical committee, dnr 2013/70.

Perceptual Assessment

Voice variable definitions based on the Stockholm Voice Evaluation Approach^{1,12} were modified according to the anatomy of the laryngectomees:

Rough: low-frequency aperiodicity, presumably related to some kind of irregular neoglottis vibration.

Breathy: the neoglottis is vibrating but somewhat abducted, which creates an audible turbulent noise related to the insufficient closure.

Hyperfunctional/tense: voice sounds strained due to compression/constriction of the neoglottis during phonation.

Gurgly: wet hoarseness/liquid voice quality.

Three experienced speech and language pathologists (SLP) made the voice perceptual assessment, randomly, 3 times per patient. Intra-listener and inter-listener reliability were evaluated.

The SLP registered 6 variables. In the first 2 variables, quality and intelligibility, 3 options were available: good (=1), reasonable (=2), and poor (=3). The 3 other variables are commonly used for perceptual assessment of all kinds of voice patients and voice disorders (hyper functional/tense, breathy, rough), and the sixth variable, gurgly, is used in descriptions of laryngectomees' voices.^{1,12} In variables 3 to 6, a 100 mm visual analogue scale (VAS) was used.

High-Speed Camera Examination

The system consisted of a personal computer and a camera head used in combination with a 70° rigid endoscope (HRES Endocam, model 5562.9 colour, R. Wolf, Knittlingen, Germany) and a 300 W cold light source. This system records images at a rate of 2000 or 4000 frames per second; in this study, 2000 frames per second were used. Patients were filmed while producing a sustained /ae/ or /e/ sound. Local anaesthesia was not routinely used. The variables used for visual assessment of digital HSC recordings of the PES have been described by Van As et al¹⁰:

- Saliva: Amount of saliva present at the neoglottis that could impair the visibility. Graded as: none, little, moderate, much, obstructing.
- Neoglottis visibility: The origin of the neoglottis was judged as being visible when the starting point of the vibration could be identified, not visible when only the final part of the travelling vibration could be seen or when the origin of the neoglottis could not be identified. Described as: visible, non visible.
- Neoglottis shape: Contour of the lumen during the open phase of vibration: circular, triangular, split side-to-side, anterior-posterior split, irregular, non assessable.
- Vibration location: Predominant site of vibration. Posterior, anterior, lateral, circular, nonassessable.
- Mucosal wave: Differentiation of a mucosal wave from the vibration of the neoglottic wall, in analogy to the traveling wave on vocal folds. Described as: regular, irregular, non assessable.
- Vibration regularity: Visual impression of the regularity of the vibration. Graded as: regular, irregular, non assessable.

- Closure phase: Duration of the open or closed phase of the neoglottis in relation to the complete cycle of vibration. Open, equal, close, non assessable.

Videomanometry

This examination was performed with the patient seated, using a high-resolution, solid-state transducer system (ManoScan-360, Sierra Scientific Instruments, Los Angeles, California, USA). The catheter, 4.2 mm in diameter, has 36 sensors spaced 1 cm apart from each other, and every sensor contains 12 measuring points. It was introduced through the nose after applying Xylocain gel 2% (Astra Zeneca) in order to reduce patient discomfort. All participants were instructed to swallow 10 ml of water-soluble contrast (Barium contrast medium, 240 mg/ml, 60% weight/volume) 3 times. Time for examination was less than 10 minutes, total fluoroscopy time was less than 100 seconds, and radiation dose was 0.2 mSv.

Variables analyzed during swallowing:

- resting PES pressure
- residual pressure during PES opening
- pharyngeal contraction pressure, 3 cm cranial to PES (= pressure at the level of the pharyngeal constrictor)
- esophageal peristaltic contraction pressure (= mean value at 3 and 7 cm cranial to lower esophagus sphincter).

Variables analyzed during phonation:

- pressure at PES, pharynx (3 cm cranial to PES), proximal esophagus (3 cm caudal to PES), distal esophagus (7 cm cranial to lower esophagus sphincter)
- craniocaudal length of the PES.

Voice Perceptual Assessment Related to High-Speed Camera Examination and High-Resolution Videomanometry

For the group of patients with good/reasonable voice quality according to the voice assessment made by the SLPs, we looked for associations among voice variables; between voice quality, mucosal wave, and vibration regularity in HSC recordings; between voice quality and phonation pressures; between phonation pressures, amount of saliva, mucosal wave, and vibration regularity in HSC recordings; and between voice quality and intelligibility, postoperative time, and age.

Statistics

Intraclass correlation coefficients (1-way/2-way, random, absolute agreement) were calculated to assess intra- and

Table 2. Intralistener and Interlistener Reliability Results for SLP-1, SLP-2, and SLP-3.^a

	Intralistener SLP-1	Intralistener SLP-2	Intralistener SLP-3	Interlistener SLP-1, -2, -3
Quality	0.98 (0.97-0.99)	0.98 (0.94-0.99)	0.95 (0.89-0.98)	0.96 (0.89-0.98)
Intelligibility	0.92 (0.82-0.97)	0.94 (0.84-0.98)	0.98 (0.95-0.99)	0.98 (0.97-0.99)
Rough	0.90 (0.70-0.95)	0.95 (0.88-0.98)	0.89 (0.73-0.96)	0.50 ^b (0.33-0.84)
Breathy	0.94 (0.85-0.98)	0.96 (0.90-0.98)	0.85 (0.63-0.95)	0.61 ^c (0.02-0.87)
Hyperfunctional	0.96 (0.90-0.99)	0.98 (0.94-0.99)	0.96 (0.90-0.99)	0.94 (0.85-0.98)
Gurgly	0.93 (0.83-0.98)	0.97 (0.94-0.99)	0.96 (0.91-0.99)	0.94 (0.85-0.98)

^aPresented as intraclass correlation coefficients; all presented $P < .005$ except where noted. Confidence intervals are presented in parentheses.

^b $P = .079$.

^c $P = .025$.

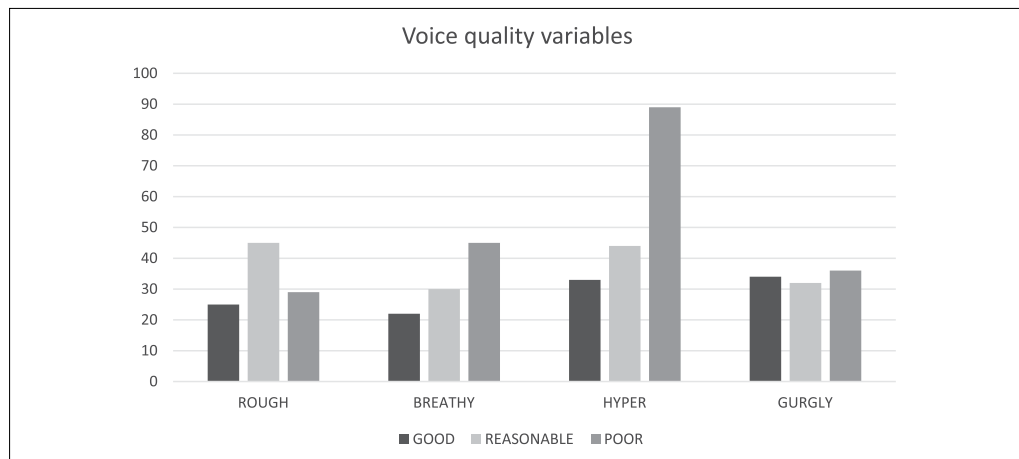


Figure 1. Mean value of voice quality variables, related to the voice assessment made by the speech and language pathologist. 0-100 = Visual Analogue Scale in mm. Hyper, Hyperfunctional.

interrater reliability; the voice recordings were assessed randomly 3 times by the SLPs. Spearman correlation was used to check association between voice, HSC, and HRVM variables. P values $\leq .05$ (2-tailed) were regarded as significant.¹³ All data were analyzed using Statistical Package for the Social Sciences (SPSS) 23 Mac version.

Results

Voice Perceptual Assessment

Results regarding intra- and inter-listener reliability are presented in Table 2. The SLPs rated 4 patients with good, 7 with reasonable, and 3 with poor voice quality; 5 had good, 6 reasonable, and 3 poor voice intelligibility. The other voice variables were rated as follows: rough (mean 36 ± 14 mm), breathy (mean 31 ± 14 mm), hyperfunctional (mean 50 ± 23 mm), and gurgly (mean 34 ± 22 mm). For comparison of variables depending on voice quality, see Figure 1.

High-Speed Camera Examination

Recordings were obtained in all but 2 patients, who did not tolerate the telaryngoscope.

The HSC assessment results are shown in Table 3. Regarding participants with good/reasonable voice, the neoglottis was visible in all the patients. They showed a strong mucosal wave, and the shape of the neoglottis was circular in 5 of 9 participants. The vibration was seen in the whole circumference of the neoglottis in 6 of 9 participants, and they presented less saliva than those with poor voice quality. More HSC assessment results are shown in Table 3.

High-Resolution Videomanometry

The mean and median values of the HRVM variables during phonation and swallowing are presented in Table 4. Mean phonation pressure at PES was 39 mmHg, 43 mmHg in the proximal esophagus, and 57 mmHg in the distal esophagus

Table 3. Results of Evaluation of the Characteristics of the Neoglottis With High-Speed Camera Related to the Voice Assessment Made by the Speech and Language Pathologist.

Variables	Judgment	Total N = 12	Good/Reasonable Voice N = 9	Poor Voice N = 3
Saliva	None	1	1	—
	A little	6	6	—
	Moderate	3	1	2
	Much	1	1	—
	Obstructing	1	—	1
Neoglottis origin	Visible	11	9	2
	Not visible	1	—	1
Neoglottis shape	Circular	5	5	—
	Triangular	1	1	—
	Split side-to-side	3	2	1
	Split anterior-posterior	1	—	1
	Irregular	0	—	—
	Not assessable	2	1	1
Location of the visible vibration	Posterior	3	2	1
	Anterior	0	—	—
	Lateral	1	—	—
	All walls	7	6	1
	Not assessable	1	1	—
Mucosal wave	Strong	10	8	2
	Weak	1	1	—
	Absent	1	—	1
Vibration regularity	Regular	6	4	2
	Irregular	5	5	—
	Not assessable	1	—	1
Closure phase	Open	4	4	—
	Equal	2	—	2
	Closed	3	3	—
	Not assessable	3	2	1

for all the participants in this study. The HRVM revealed low resting pressure at the PES (17 mmHg) and low esophageal peristaltic contraction pressure (53 mmHg) during swallowing.

Voice Perceptual Assessment Related to High-Speed Camera Examination and High-Resolution Videomanometry

For the group of patients with good/reasonable voice quality according to the voice assessment made by the SLPs, a positive correlation between voice quality and voice intelligibility ($r_s = 0.8, P = .002$) was found. In addition, a positive correlation between roughness and worse voice quality ($r_s = 0.6, P = .04$), hyperfunction and poor intelligibility ($r_s = 0.6, P = .04$), poor quality and long time since TL ($r_s = 0.7, P = .01$), and poor voice quality and old age ($r_s = 0.6, P = .05$) was found. No other significant correlations were found between the HSC, voice, and phonation pressure variables.

Discussion

The European Laryngological Research group recommended voice perceptual rating as an essential method in voice assessment.^{14,15} Variables based on the modified Stockholm Voice Evaluation Approach were chosen for our study. Voice perceptual assessment made by our SLPs showed high intra-listener reliability when compared to other studies⁹ (see Table 2). This suggests they have a stable, internalized baseline for the optimal TE speech against which to evaluate these patients.^{7,8} Inter-listener reliability was high, except in the variable rough (0.50, $P = .079$), which should be taken in account when interpreting the results for this variable in Figure 1. Patients included in this study had a functional TE voice, no swallowing problems, and rated themselves as good/reasonable TE speakers, with good intelligibility on the telephone and no need for treatment. However, 3 of them were considered poor speakers according to the SLPs' voice perceptual assessment. This shows how the perception and expectations of patients and health professionals may differ.^{16,17} To include patients with

Table 4. Pressures in Good/Reasonable, Poor Speakers (as Judged by Perceptual Analysis) and All Participants in the Study.^a

	Good/Reasonable N = 11	Poor N = 3	All Participants N Total = 14
Age	69 ± 11 (73)	77 ± 10 (79)	70.7 ± 11 (73)
PES length	14 ± 6 (10)	11 ± 7 (10)	14 ± 7 (10)
Phonation 1	22 ± 11 (20)	7 ± 2 (6)	18 ± 11 (19)
Phonation 2	39 ± 18 (34)	39 ± 15 (41)	39 ± 17 (37)
Phonation 3	39 ± 20 (42)	58 ± 31 (73)	43 ± 23 (43)
Phonation 4	54 ± 18 (42)	68 ± 24 (88)	57 ± 19 (59)
Pharyngeal pressure	77 ± 56 (54)	133 ± 97 (48)	89 ± 67 (68)
Resting pressure	17 ± 9 (16)	16 ± 11 (17)	17 ± 9 (17)
Residual pressure	10 ± 5 (4.5)	4 ± 1 (4)	9 ± 5 (10)
Esophageal pressure	50 ± 31 (36)	68 ± 50 (47)	53 ± 34 (41)

^aMean values, median in parentheses. During phonation: PES = pharyngoesophageal segment; Phonation 1 = phonation pressure 3 cm cranial to PES; Phonation 2 = pressure at PES; Phonation 3 = phonation pressure 3 cm caudal to PES; Phonation 4 = phonation pressure 7 cm cranial to lower esophagus sphincter. During swallowing: pharyngeal, resting, residual, and esophageal pressures. All participants = good/reasonable + poor voice quality, according to the voice assessment made by the speech and language pathologist.

good/reasonable voice quality, a more detailed and validated self-reported questionnaire, such as the Voice Handicap Index or the Self Evaluation of Communication Experiences after Laryngectomy (SECEL), might help.^{9,18,19} According to the results shown in Figure 1, those patients with poor voice quality showed the highest values in the variable hyperfunction. This complies with the results of Hurren et al⁸ on the relationship between severe hyper/hypotonicity and poor voice quality. For those with good/reasonable voice quality, the correlation between poor voice quality and long time since the operation may be explained by the old age of the patients, which is in line with the results presented by Op de Coul et al.²⁰ Given the time-consuming nature of the perceptual assessments, it might be reasonable to consider in future studies new methods such as the acoustic analysis with signal typing to assess voice quality and even automatic intelligibility assessment.²¹⁻²³

We chose HSC to obtain information on the vibratory pattern of the neoglottis since imaging of the PES should be independent of triggering based on the fundamental frequency as in stroboscopy. Patients with good/reasonable voice quality showed a strong mucosal wave, and the shape of the neoglottis was mainly circular. The vibration was seen in the whole circumference of the neoglottis (see Table 3). These results highlight the variety in the morphology and function of the PES. In 1999, Van As et al¹⁰ evaluated 35 TE speakers with HSC and found a strong mucosal wave in most

of the participants with vibration located mainly at the whole circumference of the neoglottis. They used a similar speech task as in this study (participants were asked to produce a sustained /a/) but described a split side-to-side as a predominant shape of the neoglottis, which seems closer to the normal anatomy of the vocal cords. Lundström and Hammarberg² assessed 3 TE speakers with HSC and described the vibration as located at the posterior part of the neoglottis. This may be explained by the fact that the subjects were recorded with a fiberoptic laryngoscope and their speech task was to produce voiced and voiceless stop consonants and perhaps by differences of tumor morphology and surgical techniques, not described in their study. Recent technical progress in HSC, such as the use of a 2-point laser triangulation system, allows measurements of vocal fold displacements during vibration as well as the vocal fold length.²⁴ In 2014, Huttner et al²⁵ developed an automated objective quantification of the PES morphology and function with HSC. These advances may add accuracy to future endoscopic evaluation of the neoglottis with HSC.

The HRVM confirmed low resting pressure at the PES (17 mmHg) and low esophageal peristaltic contraction pressure (53 mmHg) during swallowing, which characterizes laryngectomees in comparison to normal subjects.²⁶⁻²⁸ None of the patients included in this study reported dysphagia, which may be explained by the fact that no additional postradiation/postoperative complications at PES were found. The pharyngeal contraction pressure was lower in patients with good/reasonable voice (77 mmHg) than those with poor voice quality (133 mmHg); although both values are included in the normal range of pharyngeal contraction pressure of healthy volunteers, this pressure difference might play a role in the voice quality.^{17,26} A decreasing phonation pressure from the distal esophagus to the pharynx was revealed in good/reasonable and poor speakers (Table 4). Mean phonation pressure at PES was 39 mmHg, 43 mmHg in the proximal esophagus, and 57 mmHg in the distal esophagus for all the participants in this study (Table 4). These values are similar to those presented by Takeshita-Monaretti et al⁵ and may indicate that a harmonious decreasing pressure along the entire esophagus up to the PES and pharynx is necessary for a functional TE voice production. This prevents the descent of air into the stomach and confirms the contribution of the esophagus in the control of the airflow necessary to generate pressure below the PES that sets the mucosa of the neoglottis into vibration. The alaryngeal voice production might be seen as an aerodynamic-myoelectric event, and the adjustment of the PES is not as consistent as in laryngeal voice. The use of HRVM at PES and esophagus simplifies and adds accuracy to pressure measuring, which might be useful in rehabilitation and treatment of TE speakers.

Conclusions

This is the first study combining high-speed camera recordings, high-resolution videomanometry examination, and voice perceptual assessment. The HRVM is the most quantifiable of the 3 methods used. Functional TE speakers presented low resting pressures at the pharyngoesophageal segment and low esophageal peristaltic contraction pressure in comparison to normal subjects. The phonation pressure decreased from the distal esophagus to the pharynx, which indicates that the esophagus contributes to the airflow necessary to produce TE voice. Additional anatomical and functional information about the PES was obtained with HSC recordings and voice assessment.

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Paper IV





The Pharyngoesophageal Segment in Laryngectomees with Non-Functional Voice: Is It All about Spasm?

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Abstract

Objective: The aim of the present study was to characterize the pharyngoesophageal segment in non functional tracheoesophageal speakers and to confirm that the patients responded to treatment with decreased pressures, better voice and increased neoglottis vibration.

Methods: Voice perceptual assessment, high-resolution videomanometry of swallowing and phonation and high-speed camera recording during phonation provided information about anatomy and function of the pharyngoesophageal segment before and 1 month after treatment with balloon dilatation and/or botulinum toxin.

Results: High resolution videomanometry revealed 12 patients with phonation pressure higher than 20 mm Hg before treatment: 2 patients with pressure between 20-45 mm Hg, 5 patients with pressure between 45-66 mmHg and 5 patients with pressure higher than 66 mm Hg. Eight of twelve patients reported clinical improvement after treatment. Their phonation index (defined as the ratio between phonation pressure at pharyngoesophageal segment and distal oesophagus), phonation pressure and residual pressure at the pharyngoesophageal segment decreased after treatment. There was no significant difference between voice variables values before and after treatment. High-speed camera recordings revealed a wide variation in the anatomical and functional characteristics of the neoglottis.

Conclusions: Normal pressure of the PES during phonation is an important factor for successful sound emission in TE speakers. Others aspects as fibrosis at pharyngoesophageal segment and oesophageal peristalsis should be considered.

Keywords

Balloon dilation; Fibrosis; Tracheoesophageal

Abbreviations

BT: Botulinum Toxin; HRVM: High Resolution Videomanometry; HSC: High-Speed Camera; Mmhg: Millimetres of Mercury; PES: Pharyngoesophageal Segment; SLP: Speech And Language Pathologist; TL: Total Laryngectomy; TE: Tracheoesophageal; TEP: Tracheoesophageal

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Introduction

Total laryngectomy (TL) is the treatment of choice for advanced laryngeal cancer. Speech therapy and prosthetic voice rehabilitation are considered the gold standard for restoration of voice production after TL. The acquisition of tracheoesophageal (TE) speech requires anatomic and physiologic conditions that allow the passage of the air from the lungs through the tracheoesophageal prosthesis (TEP) and the pharyngoesophageal segment (PES). Additionally, the lining mucosa of the PES should be capable to vibrate sufficiently to produce the voice [1,2].

Normal pressure of the PES during phonation is believed to be important for a successful sound emission [3]. In general, the muscle activity of the PES is a protective reflex against reflux, but in patients with TEP it constitutes a significant impediment to voice production and rehabilitation. PES hypertonicity is the most common cause of failure in oesophageal (38%) and TE (35%) voice [4]. Muscle spasm at the PES causes an interruption of airflow from the oesophagus to the pharynx during phonation. This disrupts the vibration of the mucosa and prevents the voice production [5]. Singer and Blom studied 129 laryngectomized patients using the air insufflation test in combination with videofluoroscopy and concluded that spasm at PES needs to be treated in order to improve TE speech Singer et al. [6]. Several potential treatments for PES spasm have been described: Myotomy of the middle and inferior constrictor muscles of the pharynx and the cricopharyngeal muscle, partial neurectomy of the pharyngeal plexus and chemical denervation of the PES with botulinum toxin (BT) [6]. BT injection in the PES is a simple, quick and relatively cheap in-the-office procedure with effects lasting beyond two years in some cases [7-11]. Therefore, BT injection appears to be a reasonable and less invasive alternative. But, it is important to assess the sagittal diameter at PES, because the effect of BT may negatively affect the swallowing function. We establish 5 mm as the limit value of the sagittal diameter at PES thus patients in which the diameter of the PES is smaller than 5 mm should be treated with balloon dilation (BD) before BT injection [12].

Aims of the Study

The present study is a characterization of the PES in TE speakers, who rated themselves as having a non-functional TE voice. The aims of the study were:

- To use voice perceptual assessment, high resolution videomanometry (HRVM) and high-speed camera (HSC) recordings to characterize non-functional TE speakers.
- To confirm if the patients responded to treatment with decreased pressures, better voice and increased neoglottis vibration.
- To investigate if the phonation index, which is the ratio between phonation pressure at PES and phonation pressure at the distal oesophagus, changes after treatment and if this ratio could explain the difference between functional and non-functional TE speakers.

Material and Methods

We recruited 13 patients who reported themselves as non-functional TE speakers (no voice, not able to talk on the telephone,

phonasthenia). They were 9 men and 4 women, 5 had no voice. All except 2 patients reported dysphagia, Table 1. They were all former smokers with a mean age of 73 years (range: 61-82 years). All but two received radiotherapy, Table 1. Mean time after surgery was 30 months, median 12 months (range: 6-156 months), Table 1. All were diagnosed with squamous cell carcinoma, except two that had a condrosarcoma. Cricopharyngeal myotomy and insertion of the TEP, Provox®, was performed in the same session as the laryngectomy in all patients. They finished their medical/surgical treatment at least 3 months before being included in the study and presented no evidence of recurrent disease. Their stoma was covered with a heat and moisture exchanger valve. All participants signed informed consent and underwent clinical evaluation by an otolaryngologist. Those patients with a PES anteroposterior diameter smaller than 5 mm and dysphagia were treated with BD previous to the BT injection. High resolution videomanometry, voice perceptual assessment and visual assessment of digital high speed recordings of the neoglottis were made before and 1 month after BD and/or BT injection.

The study was approved by the local ethical committee, dnr 2013/70 (Table 2).

Perceptual assessment

Three experienced speech and language pathologist (SLP) made the voice perceptual assessment, three times per patient, before and 1 month after treatment.

In order to complete the voice perceptual assessment, the SLP registered six variables. In the first two variables, quality and intelligibility, three options were available: good (=1), reasonable (=2), poor (=3). The three other variables are commonly used for perceptual assessment of all kind of voice patients and voice disorders (hyper functional/tense, breathy, rough) and the sixth variable, gurgle, is used in descriptions of laryngectomees voices [8]. In variables 3 to 6 a visual analogue scale (VAS) was used. Voice variables definitions based on the Stockholm Voice Evaluation Approach [13] were modified according to the anatomy of the laryngectomees:

Table 1: Patient's data on dysphagia, treatment, radiotherapy and postoperative time.

Patient	Dysphagia	Radiotherapy	TNM	Postoperative time
1	YES	POSTOP	T4N0M0	10
2	NO	PREOP	rT2N0M0	20
3	YES	PREOP	rT2N0M0	6
4	YES	PREOP	rT2N0M0	156
5	YES	NO	rT2N0M0	14
6	YES	PREOP	rT2N0M0	26
7	YES	POSTOP	T3N0M0	18
8	YES	PREOP	rT4N0M0	7
9	YES	NO	T4N0M0	8
10	NO	POSTOP	T4N0M0	12
11	YES	PREOP	rT3N0M0	92
12	YES	PREOP	rT4N0M0	7
13	YES	PREOP	rT4N0M0	7

The postoperative time is calculated in months. According to the recommendations of the "Swedish Guidelines for Treatment of Head & Neck cancer", patients received curative RT for a previous larynx cancer, which is named as preop. However, they presented recurrence and required total laryngectomy (this is represented as a "r" in the TNM). Patients received postoperative radiotherapy depending on the results of the pathology report or the findings during the operation.

Rough: Low-frequency aperiodicity, presumably related to some kind of irregular neoglottis vibration.

Breathy: The neoglottis is vibrating, but somewhat abducted, which creates an audible turbulent noise related to the insufficient closure (Table 3).

Hyper functional/tense: Voice sounds strained, due to compression/constriction of the neoglottis during phonation.

Gurgly: Wet hoarseness/liquid voice quality

Videomanometry

This examination was performed with the patient seated, using a high-resolution solid-state transducer system (ManoScan-360, Sierra Scientific Instruments, Los Angeles / CA, USA). The catheter, 4.2 mm in diameter, has 36 sensors spaced 1 cm apart from each other and every sensor contains 12 measuring points. All participants were instructed to swallow 10 ml of non water-soluble contrast (Barium contrast medium, 240 mg/ml, 60% weight/volume) three times. The catheter was introduced through the nose after applying Xylocain gel 2% (Astra Zeneca) in order to reduce patient discomfort. Time for examination was less than 10 min, total fluoroscopy time was less than 100 sec and radiation dose 0.2 mSv. All measures are in millimetres of mercury (mmHg).

Table 2: Intralistener and interlistener reliability of the voice perceptual assessment.

	Intra-listener SLP-1	Intra-listener SLP-2	Intra-listener SLP-3	Inter-listener SLP-1,-2,-3
Quality	0.93	0.97	0.99	0.92
Intelligibility	0.96	0.99	0.98	0.97
Rough	0.90	0.95	0.77	0.55*
Breathy	0.93	0.97	0.94	0.29*
Hyper Functional	0.92	0.91	0.96	0.69*
Gurgly	0.97	0.94	0.90	0.76

Intraclass correlation coefficients; all presented $p < 0.005$ except a: $p = 0.079$, b: $p = 0.025$ and c: $p = 0.03$. Speech and language pathologist=SLP.

Table 3: Pressure values in functional versus non functional speakers before and after treatment.

	Functional speaker	Non-functional speaker before treatment	Non-functional speaker after treatment
PES length		14.7 (15)	13.5 (15)
Phonation 1		48.3 (45)	35.8 (32)
Phonation 2	38.1	64.3 (64)	47.4 (45)
Phonation 3	43.3	55.4 (58)	46.8 (47.5)
Phonation 4	53.6	59.5 (60)	58.2 (64)
Phonation index	0.71	1.08	0.81
Pharynx pressure		167.7 (169)	133.2 (128)
Resting pressure		25.1 (26)	22.5 (18)
Residual pressure		30 (27)	17.4 (15)
Oesophageal pressure		53.5 (40)	50 (32)

Phonation: PES=Pharyngoesophageal segment, Phonation1=Phonation pressure 3 cm cranial to PES, Phonation 2=pressure at PES, Phonation 3=Phonation pressure 3 cm under caudal to PES, Phonation 4=Phonation pressure 7 cm cranial to lower oesophagus sphincter. Phonation index=Ratio between the phonation pressure at PES and the phonation pressure at distal oesophagus. Swallowing: Pharynx pressure, Resting and Residual pressure at PES, Oesophageal pressures. Mean values, the median value is represented in parenthesis. Functional speaker's phonation pressures from Takeshita et al. [28].

Variables analysed during swallowing:

- Resting PES pressure.
- Residual pressure during PES opening.
- Pharynx contraction pressure 3 cm cranial to PES (= pressure at the level of the pharyngeal constrictor).
- Oesophagus peristaltic contraction pressure (= mean value at 3 and 7 cm cranial to the lower oesophagus sphincter).

Variables analysed during phonation:

- Pressure at PES, pharynx (3 cm cranial to PES), proximal oesophagus (3 cm caudal to PES), distal oesophagus (7 cm cranial to the lower oesophagus sphincter).
- Phonation index (=phonation pressure at PES/phonation pressure at the distal oesophagus)
- Craniocaudal length of the PES.

High-Speed camera examination

The system consisted of a computer and a camera head used in combination with a 70° rigid endoscope (HRES Endocam, model 5562.9 colour, R.Wolf, Knittlingen, Germany) and a 300 W cold light source. This system records images at a rate of 2000 or 4000 frames per second. In this study 2000 frames per second were used. Patients were asked to stick out their tongues to reveal the opening of the PES and to produce a sustained /ae/ or /e/ sound. Local anaesthesia was not routinely used. The variables used for visual assessment of digital HSC recordings of the PES, have been described by Van et al. [14]:

- Saliva: Amount of saliva present at the neoglottis that could impair the visibility. Graded as: None, little, moderate, much, obstructing.
- Neoglottis visibility: The origin of the neoglottis was judged as being visible when the starting point of the vibration could be identified, not visible when only the final part of the travelling vibration could be seen or when the origin of the neoglottis could not be identified. Described as: Visible, non visible
- Neoglottis shape: Contour of the lumen during the open phase of vibration: Circular, triangular, split side-to-side, anterior-posterior split, irregular, non assessable.
- Vibration location: Predominant site of vibration. Posterior, anterior, lateral, circular, non assessable.
- Mucosal wave: Differentiation of a mucosal wave from the vibration of the neoglottic wall, in analogy to the travelling wave on vocal folds. Described as: regular, irregular, non assessable.
- Vibration regularity: Visual impression of the regularity of the vibration. Graded as: Regular, irregular, non assessable.
- Closure phase: Duration of the open or closed phase of the neoglottis in relation to the complete cycle of vibration. Open, equal, close, non assessable.

The assessment of the recordings was made by two experienced specialists in Phoniatrics and Laryngology, who evaluated the recordings in three different sessions and rated them after reaching consensus.

Botulinum toxin injection

Topical anaesthetic with vasoconstrictor (Lidocain-Nafazolin APL 34 mg/ml + 0.17 mg/ml) was applied in the nostril and the patient swallowed lidocain (Xylocain viscous 20 mg/ml; Astra Zeneca,

Södertälje, Sweden) to anesthetize the pharynx. We used an injection needle (Posi-Stop from Hobbs Medical inc.) through a channel fiberlaryngoscope, to inject the BT at three points (two lateral and one posterior) in the visible cranial part of the PES. We used freshly reconstituted, purified botulinum toxin type A (Botox, Allergan Inc, Irvine, California) at a 2.5- mouse units (MU)/0.1 mL concentration at a total dose of 30-50 units. All patients were discharged directly.

Balloon dilatation

BDs were performed in the outpatient clinic. Topical anaesthetic with vasoconstrictor (Lidocain-Nafazolin APL 34 mg/ml + 0.17 mg/ml) was applied in the nostril and lidocain (Xylocain 10 mg/ml; Astra Zeneca, Södertälje, Sweden) was sprayed into the throat to anesthetize the pharynx. Dilatations were performed with controlled radial expansion balloons with diameter between 8-14 mm, during 2- 2.5 min through a channel fiberbronchoscope. The procedure was made twice in all patients, with 6-week interval between dilatations. All patients were discharged directly.

Statistics

Intraclass correlation coefficients were calculated to assess intra and inter-rater reliability. Wilcoxon signed rank test was used to compare results pre/post treatment. P values ≤ 0.05 (two-tailed) were regarded as significant [15]. All data were analysed using Statistical Package for the Social Sciences (SPSS) 23 © Mac version.

Results

We recruited 13 patients, but one died prior to treatment due to complications related to liver cirrhosis. Six received BT in doses between 25-45 IU. Four had an anterior posterior diameter at PES smaller than 5 mm and reported dysphagia, they were treated with BD twice and experienced clinical improvement and thus they were not treated with BT, Table 4. Two were treated with BD and BT in doses between 25-45 IU. Eight patients reported clinical improvement in voice and dysphagia after treatment, four reported no clinical improvement, two of them left the study.

Voice perceptual assessment

Results regarding intra and inter-listener reliability are presented in Table 2. Five subjects had no voice before the treatment. The others were rated by the SLP: 1 had good, 4 had reasonable and 3 had poor voice quality; 2 had good, 5 had reasonable and 1 had poor voice intelligibility. Voice quality results are presented in Table 4. Wilcoxon test showed no difference between voice variables before and after treatment. Hypertonicity was the variable with highest values. For comparison of variables rough, breathy, hypertonic, gurgly before and after treatment (Figure 1).

High-Speed camera examination

Results regarding intra-rater reliability are presented in Table 5. Recordings have been obtained in seven patients before treatment and in ten patients after treatment. Wilcoxon sign rank test showed no difference between HSC recordings before and after treatment. Results regarding neoglottis mucosal wave and vibration regularity before and after treatment are included in Table 4.

Videomanometry

Wilcoxon sign rank test revealed significant differences before and after treatment in phonation index PES/oesophagus, $Z = -2.8$ ($p = 0.005$), phonation pressure at PES, $Z = -2.6$ ($p = 0.009$) and residual

Table 4: Response to treatment.

Pat	Treat	Clinical improvement	Voice quality pre→post	Neoglottis vibration pre→post	Neoglottis mucosal wave pre→post	Phonation Index pre→post	Phonation pressure at PES	Residual Pressure pre→post
1	BT	NO	4 →4	0 NA	C ABSENT	3.3 →2.2	96 92	59 →25
2	BT	YES	4 →3	REGREG	STRONG→STRONG	1.6 →0.5	95 → 38	29 →13
3	-	-	3	-	-	0.9 -	80 -	27
4	BT	YES	3 →2	IRREG →NA	WEAK STRONG	0.7 →0.6	20 → 22	8 →11
5	BD+BT	YES	3 →2	0 → NA	0 → STRONG	0.7 →0.6	30 → 20	17 →15
6	BD	YES	2 →2	0 → REG	0 → WEAK	1 →0.8	61 60	43 30
7	BT	NO	4 →4	NA → 0	WEAK → 0	1.9 → -	101 → -	18
8	BD+BT	YES	2 →2	NA REG	ABSENT→WEAK	0.9 →0.7	62 → 50	19 →13
9	BT	NO	2 →3	IRREG→ REG	STRONG→WEAK	0.8 →0.6	59 →40	9 →8
10	BT	NO	4 →4	-	-	0.8 → -	42 -	44
11	BD	YES	1 →1	REG REG	WEAK WEAK	1 →0.8	87 →70	64 →25
12	BD	YES	2 →2	NA IRREG	ABSENT→WEAK	0.8 →0.6	54 →50	35 →15
13	BD	YES	4 →3	0 →NA	0 → STRONG	0.6 →0.5	49 31	17 18

1= Good, 2= Reasonable, 3= Poor, 4= No voice. BT= Botulinum toxin, BD= Balloon dilatation, Pre and post: Pre and postoperative, NA= Non assessable. Clinical improvement according to patient's self report, Voice pre and post: Voice quality pre and post-treatment according to SLPs assessment. When the high speed camera recording could not be done, it is indicated as "0" in the columns related to neoglottis vibration and mucosal wave. When the patient left the study it is indicated as a "-".

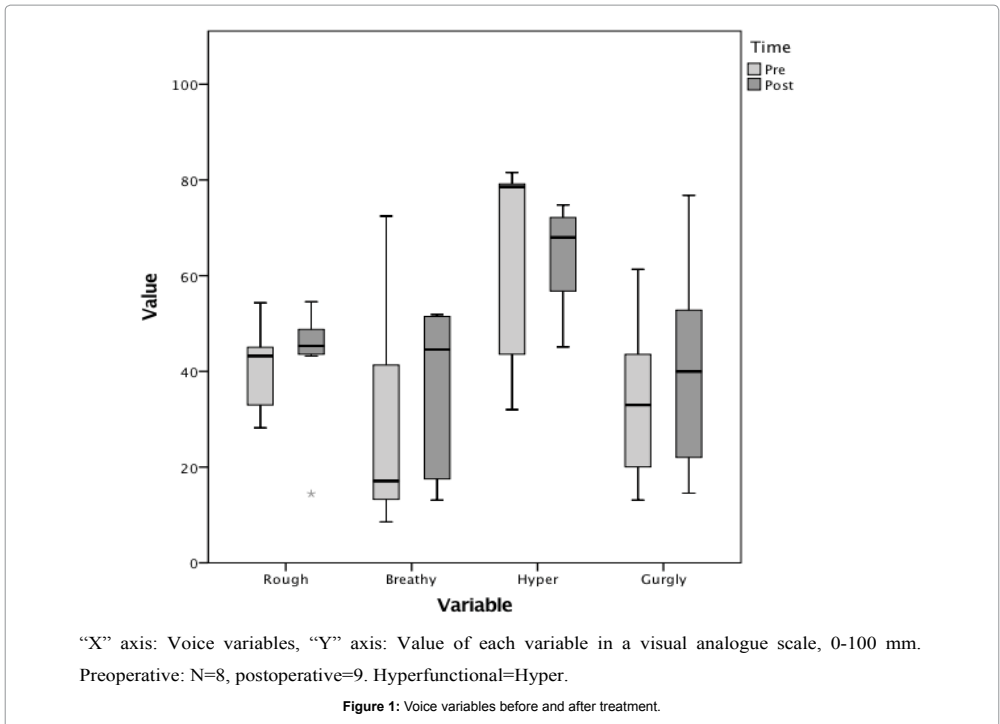


Table 5: Intra-rater reliability as intraclass correlation coefficients.

	Saliva	Neoglottis visibility	Neoglottis shape	Vibration location	Mucosal wave	Vibration regular.	Closure phase
Intra rater	0.87 p=0.001	1 p<0.0005	0.64 p=0.05	0.78 p=0.009	0.98 p<0.0005	0.76 p=0.01	0.83 p=0.004

pressure at PES, $Z = -2.2$ ($p = 0.03$). Group pressure values during swallowing and phonation are presented in Table 3. For individual phonation index, phonation pressure at PES and residual pressure values see Table 4. Six of the patients had an anteroposterior diameter less than 5 mm and required BD.

Discussion

Success rates of TE voice can be as high as 90 % Op de Coul et al. [16] Due to the impact that the voice has on the quality of life, voice rehabilitation after TL may be a major challenge [17]. The patients included in this study reported themselves as non functional TE speakers and required treatment. A multidimensional evaluation of the PES using voice perceptual assessment, HRVM and HSC recording, was made in order to understand the mechanism of their voice impairment and their response to the treatment.

Perceptual assessment of the voice is a key to manage voice rehabilitation in laryngectomees. Variables based on the modified Stockholm Voice Evaluation Approach were chosen to make the assessment in our study [13]. Voice perceptual assessment made by the SLPs showed high intra-listener reliability when compared with other studies [18]. Before treatment, four patients were considered reasonable speakers and one was rated as a good speaker according to the SLPs voice perceptual assessment, but these patients rated themselves as non functional TE speakers, Table 4. This shows how the perception and the expectations of patients and health professionals may differ [19]. The inter-rater reliability was low for variables rough (0.55 $p=0.079$) and breathy (0.29, $p= 0.025$), Table 2, and points out that perceptual voice assessment after TL may be difficult. Acoustic voice assessment may help to detect differences in voice before and after treatment, since the spectrographic trace and type of signal (I, II, III or IV) may predict the contact between the anterior wall and the prominence of PES during phonation [20-22].

HSC is the only possible method to record vibrations in the neoglottis after TL, since it is not dependent on the fundamental frequency of the phonation [23]. Two of the patients could not produce any sound which is necessary in order to make a recording. Three of the patients did not tolerate the telelaryngoscope. The intra-rater reliability was high for all the variables, which might be expected in professionals with experience in using this examination method. HSC recordings revealed a wide variation in the anatomical characteristics of the neoglottis, in accordance with other studies [14,18]. Those patients who reported clinical improvement after treatment, showed a trend to more regular neoglottis vibrations and stronger mucosal waves after treatment, Table 4, although these results were not statistically significant.

In non laryngectomized subjects, phonation threshold pressure represents the minimum amount of subglottic pressure needed to initiate oscillation of the vocal folds [24]. The subglottic pressure may be estimated either indirectly, by recording air pressure and oral pressure using a mask firmly fitted over the mouth and nose [25], or

directly using a percutaneous catheter into the trachea, a translaryngeal catheter through the nose into the trachea or an intraoesophageal catheter [26,27]. During phonation the catheter is partly surrounded by air and partly squeezed by the PES and the oesophageal walls. We therefore used HRVM to measure the phonation pressure and considered that phonation pressure in TE voice is a combination of contact and intraluminal pressure. Decreasing phonation pressure from the distal oesophagus to the pharynx was found after treatment, Table 3. These results agreed with those reported by Takeshita et al. [28] regarding functional TE speakers. Morgan et al. [3] reported phonation pressure at PES between 15-20 mm Hg for functional TE speakers and in a sample of 13 persons, they found four different groups: A hypotonic group with a pressure of 11.3 mmHg, a tonic group with a pressure of 18.3 mmHg, a hypertonic group with a pressure of 45 mmHg and a spasmodic group with pressure of 66.2 mmHg. Before treatment four different groups can be seen in our sample, Table 4: 1 patient with a pressure of 20 mmHg, 2 patients with pressures between 20-45 mmHg, 5 patients with pressures between 45-66 mmHg and 5 patients with pressures higher than 66 mmHg. The spasmodic group showed higher pressures in our study, this difference might be explained by the differences between the methods used to measure the pressure. TL causes oesophageal motility impairment characterized by low contraction amplitudes and non-peristaltic contractions [29-31]. Thus, in order to improve TE speech we should consider not only the PES pressure, but also the pressure in the distal oesophagus. If the pressure in the oesophagus is too low, it will be difficult to produce TE voice. We hypothesized that there might be a phonation index, defined as the ratio between the phonation pressure at the PES and at the distal oesophagus, which might explain the difference between a functional and a non-functional TE speaker. We aimed to reduce this phonation index by treating the PES of our patients with BT and/or BD. Patients who reported improvement showed a decrease in their phonation index, Table 4.

Postoperative and post-radiotherapy changes cause fibrosis and PES stenosis, which may impair the acquisition of TE voice. This may explain why patients respond to BD and do not respond to BT injection in our study. Thus PES hypertonicity is not the only component in TE speech failure, fibrosis at PES and impaired oesophagus motility need to be considered. After TL patients must also cope with dysphagia. Stenosis at the PES occurs in 20 % of patients after TL [32], six patients had stenosis and required BD. This and the disturbance of the oesophageal peristalsis may account for the high incidence of self-reported dysphagia following TL, which is up to 85% in our study and 72 % in the literature [33].

Conclusions

This is the first study that combines voice perceptual assessment, HSC recording and HRVM to assess non-functional TE speakers. It represented a small and heterogeneous group of patients which require individualized assessment. PES hypertonicity is not the only component in TE speech failure, fibrosis at PES and oesophagus

pressure need to be considered. All except one of the patients included in the study, had phonation pressures at PES higher than 20 mmHg. After treatment with BD and/or BT the phonation index PES/oesophagus, phonation at PES and residual pressure at PES decreased and those patients reported clinical improvements.

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