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2009

## Voice Function and Quality of Life in Laryngectomees

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Institutet**



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المنارة للاستشارات

STUDIES IN LOGOPEDICS AND PHONiatrics, NO. 13

Department of Clinical Science, Intervention, and Technology  
Division of Logopedics and Phoniatrics,  
Karolinska Institutet, Stockholm, Sweden

# VOICE FUNCTION AND QUALITY OF LIFE IN LARYNGECTOMEES

Elisabet Lundström



**Karolinska  
Institutet**

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المنارة للاستشارات

**Mycket tyder på att människan är en kontinent  
som faktiskt inte alls är färdigutforskad,  
att vår bild av oss själva är högst ungefärlig  
och delvis faktiskt felritad,  
och att det är där framtidens stora  
forskningsbedrifter ligger:  
inte i att förstå elektromagnetism  
eller kosmisk strålning,  
utan oss själva.**

Fredrik Lindström, Sommar i P1 2008

## ABSTRACT

Individuals who undergo *laryngectomy*, surgical removal of the larynx, lose their normal voice. The breathing pattern is altered to permanent tracheostomal breathing. A new voice can be established by use of a segment in the lower part of the pharynx and the most upper part of the esophagus, the pharyngo-esophageal (PE) segment. This is the voice source in tracheoesophageal (TE) speech and esophageal (E) speech. Electrolaryngeal (EL) speech is an alternative speaking technique. The overall aim of this thesis was to describe the function and the effects of the PE-segment with the use of endoscopic and radiological methods, to make acoustical and audio-perceptual analyses of laryngectomees' voice and speech, and to investigate the laryngectomees' self-evaluations of voice function and quality of life.

Fifty-four laryngectomees participated in the four studies, all in all 45 TE-speakers, four E-speakers and five EL-speakers. The function of the PE-segment was studied with high-speed imaging recordings and videoradiography. Analyses were made of the vibratory pattern, the shape, the placement and the size of the PE-segment. Recorded speech samples were perceptually and acoustically analysed. Voice problems were evaluated by the use of Voice Handicap Index (VHI) and health-related quality of life was investigated by use of questionnaires from the European Organization for Research and Treatment of Cancer (EORTC).

Volitional control of the musculature in the PE-segment was seen in high-speed imaging recordings (study I). In voiceless consonants the vibrations ceased and an opening gesture in the PE-segment was observed during closure duration. In voiced consonants, the vibrations in the PE-segment continued, although with decreased amplitude compared to the surrounding vowels. These findings should be useful in a therapeutic intervention regarding the coordination of phonation and articulation.

Videoradiographical analyses of changes in shape, size and placement of the PE-segment showed predominant placement of the segment in the pharyngeal posterior wall (study II). The physiological measurements of the PE-segment showed inter-individual variations during both phonation and silence. Both TE- and E-speakers were able to make a good closure between the segment and the anterior wall of the pharynx during phonation. Placement of the segment in relation to the cervical column varied from C4 to C7. There were no significant relationships between radiological measurements of the PE-segment, perceptual analyses of voice quality, and acoustical measurements of fundamental frequency and voice intensity.

In study IV, mean values of fundamental frequency and voice intensity for TE-speakers were close to normative data, however with wide inter-speaker ranges. Speaking rate for many of the TE-speakers was slow, phrase lengths were short and the percent pause time was high, likely due to deviant breath control and manual stoma occlusion.

Protocols using visual analogue scales for perceptual ratings of TE-speech and voice proved to be reliable for carefully designed speech-language pathologist ratings. Low pitch, deviant voice quality, low speaking rates and short phrase lengths affected

assessments of overall degree of deviation, and these parameters were significantly related to the perceptual assessments.

The functional and physical subscales of VHI showed significant relationship with voice intensity, total reading time, phrase length and percent pause time. The emotional subscale of VHI showed no relation with acoustical measurements.

Perceptual assessments of TE-speech and voice showed no relationship with the speakers' self-reported voice handicap.

In study III, self-reported voice handicap was moderate for more than 50 percent of the patient group. About one third of the group rated their voice handicap as severe. Scores for the physical and functional subscales of VHI were somewhat higher compared to the emotional scale.

Ratings on the functional scales in the EORTC-questionnaire showed mean scores in agreement with normative data. The Global quality of life-scale (Global QOL) showed considerably lower scores as compared to normative data. The EORTC-questionnaire also revealed problems with smell and taste, speech, coughing, and xerostomia.

Voice handicap scores showed significant relationship with the participants' scoring of Global QOL and the functional scales in the EORTC-questionnaire. VHI-scores were also significantly related to EORTC-scores regarding breathing problems, problems with speech, social contact, pain from the head and neck area, smell and taste, and meal situations. These relationships confirm that the perceived degree of voice handicap affects the laryngectomee's participation in social activities.

As a conclusion, a combination of the EORTC-questionnaire and the VHI-questionnaire is recommended. Additional questions on tracheostomal breathing, mucus production and coughing is needed for a complete documentation of handicap and health-related quality of life for laryngectomees.

Keywords: laryngectomy, pharyngo-esophageal (PE) segment, tracheoesophageal (TE) speech, esophageal (E) speech, electrolaryngeal (EL) speech, high-speed recordings, videoradiography (VRG), perceptual analyses, acoustical analyses, Voice Handicap Index (VHI), quality of life, EORTC-questionnaires

## SAMMANFATTNING (SUMMARY IN SWEDISH)

### LARYNGEKTOMERADES RÖSTFUNKTION OCH LIVSKVALITET

Personer som genomgår operationen *laryngektomi*, borttagande av hela larynx (struphuvudet), förlorar sin normala röst och måste andas genom en permanent öppning på halsen, ett trakeostoma. Röstfunktionen kan återetableras hos många laryngektomerade genom att nedre delen av svalget (pharynx) och övre delen av matstrupen (esofagus), det pharyngo-esofageala (PE) segmentet, kan fungera som ny röstkälla.

Målsättningen med denna avhandling var att beskriva PE-segmentets funktion genom endoskopiska och röntgenologiska undersökningar, att beskriva röst- och talfunktion genom lyssnarbedömningar och akustiska analyser, samt att undersöka de laryngektomerades egna skattningar av sin postoperativa röstfunktion och hälso-relaterade livskvalitet.

Totalt femtiofyra laryngektomerade deltog i de fyra delstudierna, 45 trakeo-esofageala (TE) talare, fyra esofageala (E) talare samt fem elektrolaryngeala (EL) talare fördelade i varierande antal per studie.

PE-segmentet undersöktes ovanifrån med höghastighetsfilmning och med genomlysning från sidan med videoradiografisk undersökningsmetod. Analyser gjordes av PE-segmentets vibrationsmönster och utseende samt av dess placering i förhållande till halskotpelaren. Röstinspelningar analyserades perceptuellt av tränade lyssnare (logopeder och fonetiker) och akustiskt med datorbaserade analysprogram. Grad av rösthandikapp undersöktes med användande av enkäten Rösthandikappindex (RHI). Hälsorelaterad livskvalitet undersöktes med användande av två enkäter framtagna av European Organization for Research and Treatment of Cancer (EORTC), varav den ena är generell och den andra inriktad på problem till följd av tumör i huvud-/halsområdet.

Viljemässig kontroll av muskulaturen i PE-segmentet kunde konstateras vid analys av höghastighetsfilmer i studie I. Talarna (en E-talare och tre TE-talare) fick producera stavelser med intervokaliska tonlösa eller tonande konsonanter. Under tonlösa konsonanter avstannade vibrationerna i PE-segmentet och en kortvarig öppning i segmentet kunde också ses. I stavelser innehållande tonande konsonanter sågs kontinuerliga vibrationer genom hela stavelsen men vibrationerna under konsonantljudet var dock svagare jämfört med vibrationerna i de omgivande vokalerna. Samtliga talare uppvisade viljemässig muskulär kontroll men lyckades dock inte göra skillnad mellan tonlös och tonande konsonant i samtliga stavelser. Av lyssnarbedömningarna framkom också sådana sammanblandningar mellan tonlös och tonande konsonant för vissa talare. Analys av höghastighetsfilmer tillsammans med de akustiska analyserna kunde påvisa hur väl talarna lyckades uttala konsonantljuden. Dessa analyser verifierade de perceptuella bedömningarna. En slutsats av studien är att ökad kunskap om vilka strategier den laryngektomerade använder vid uttal av tonlösa konsonanter kan användas under tal- och röstträning med målet att öka förståelighet i talet.

Analys av PE-segmentets utseende, storlek och placering gjorda från videoradiografiska undersökningar i studie II visade på stora inter-individuella variationer bland såväl TE- som E-talare. Det framkom att samtliga talared PE-segment utgick från bakre svalgvägg och rörde sig mot svalgets framvägg under tal. Viss aktivitet sågs

även i svalgets framvägg hos några av talarna. Mätningar av förändringar i PE-segmentet från viloposition (tystnad) till röstbildning visade att såväl TE- som E-talare kunde åstadkomma en god slutning på segmentnivå (mellan bak- och framvägg i svalget). Segmentets läge i förhållande till halskotpelaren (C) varierade mellan C4 och C7. Inga signifikanta samband framkom mellan storlek och utseende på PE-segmentet, bedömd röstkvalitet och akustiska mätningar av grundtonsläge och ljudstyrkenivå.

Akustiska mätningar av grundtonsfrekvens (F0) och ljudstyrkenivå (Leq) i studie IV visade på värden för TE-talarna i överensstämmelse med värden för laryngeala talare även om variationsvidden var stor. Många TE-talare talade långsammare än normalt samt hade kort fraslängd och hög andel paustid under läsning av en standardtext. En trolig orsak till detta är det förändrade andningsmönstret samt att TE-talarna genomgående använde manuell tillstängning av sitt trakeostoma under tal.

Ett för studie IV särskilt utarbetat formulär för skattning av TE-talares röst och tal prövades. Resultaten visade god överensstämmelse inom och mellan de erfarna logopedernas bedömningar för de flesta av formulärets parametrar. Bedömd hög grad av avvikelse från normal röst visade signifikant samband med bedömningar av lågt röstläge, avvikande röstkvalitet, låg talhastighet och kort fraslängd. Lyssnarbedömningarna av talhastighet, fraslängd och röstläge visade signifikanta samband med de akustiska analyserna av dessa parametrar.

I studie III skattade drygt hälften av de 43 laryngektomerade (38 TE-talare och 5 EL-talare) sitt rösthandikapp (RHI) som medelsvårt. Närmare en tredjedel av gruppen ansåg sig ha ett allvarligt rösthandikapp. Vidare visade resultat från skattning av RHI att fysiska och funktionella röstbesvär graderades högre än emotionella röstbesvär.

De fysiska och funktionella röstbesvären, skattade av de 35 TE-talare som ingick i studie IV, visade signifikanta samband med hög röststyrka, kort fraslängd, lång lästid och hög andel pauser under läsning av standardtext. Grad av emotionella röstbesvär visade inga samband med akustiska mätningar. Lyssnarbedömningar av röst och tal visade inga samband med talarnas självskattade rösthandikapp.

I studie III visade skattningar av EORTC-enkätens funktionsskalor (fysisk, roll-, kognitiv, emotionell och social funktion) värden i nivå med data från normalpopulationen. Den övergripande skalan "Global quality of life" (Global QOL) visade dock betydligt lägre värden jämfört med normalpopulationen.

Grad av rösthandikapp (RHI) visade signifikant samband med skattning av Global QOL och skattning av funktionsskalorna i EORTC. Rösthandikapp visade sig även ha signifikant samband med andfäddhet, tal och röst i sociala sammanhang, smärta från huvud-/halsområdet, problem med lukt och smak samt matsituationer. Dessa samband bekräftar att graden av rösthandikapp påverkar deltagandet i sociala aktiviteter för den laryngektomerade.

Resultaten av enkäterna EORTC och RHI talar för att dessa enkäter bör kombineras vid undersökning av laryngektomerades livskvalitet och kommunikationsförmåga. Tillägg av frågor om problem med andning via trakeostoma, slemproduktion och besvär med hosta behövs dock för att tydligare beskriva effekterna av en laryngektomi och vad som kan påverka grad av rösthandikapp och hälsorelaterad livskvalitet.



## LIST OF PUBLICATIONS

The doctoral thesis is based on the following four original papers, which will be referred to in the text by their roman numerals.

- I. Lundström E, Hammarberg B (2004). High-speed imaging of the voicing source in laryngectomees during production of voiced-voiceless distinctions for stop consonants. *Logopedics Phoniatics Vocology*, 29:31-40.
- II. Lundström E, Hammarberg B, Munck-Wikland E, Edsberg N (2008). The pharyngo-esophageal segment in laryngectomees - videoradiographic, acoustic, and voice quality perceptual data. *Logopedics Phoniatics Vocology*, 33:115-215.
- III. Lundström E, Hammarberg B, Munck-Wikland E (2009). Voice handicap and health-related quality of life in laryngectomees: Assessments with the use of VHI and EORTC questionnaires. *Folia Phoniatica et Logopaedica*, 61: in press.
- IV. Lundström E, Hammarberg B (2009). Speech and voice after laryngectomy. Perceptual and acoustical analyses of tracheoesophageal speech related to Voice Handicap Index. Submitted manuscript.

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## LIST OF ABBREVIATIONS

DAT	Digital Audio Tape
DME	Direct Magnitude Estimation
EAIS	Equal-Appearing Interval Scale
EL-speech/speaker	Electrolaryngeal speech/speaker
ENT	Ear Nose Throat
EORTC	European Organization on Research and Treatment of Cancer
EORTC QLQ-C30	the EORTC Quality of Life Questionnaire-Core 30
EORTC QLQ-H&N35	the EORTC Quality of Life Questionnaire-Head and Neck 35
E-speech/speaker	Esophageal speech/speaker
F0	Fundamental frequency
Gy	Gray. International unit of radiation dose.
H & N	Head and Neck
HRQL	Health-Related Quality of Life
PE-segment	Pharyngo-Esophageal segment
SLP	Speech-Language Pathologist
SVEA	Stockholm Voice Evaluation Approach
TE-speech/speaker	Tracheoesophageal speech/speaker
TNM	Classification system for malignant tumors
	T = primary Tumor
	N = regional lymph Nodes
	M = distant Metastasis
VAS	Visual Analogue Scale
VHI	Voice Handicap Index
VISOR	Visual Sort and Rate method
VOT	Voice Onset Time
VRG	Videoradiography

# 1 INTRODUCTION

Laryngeal cancer primarily affects the vocal and respiratory functions, and sometimes also the swallowing function. Tumor size and location, treatment side effects and individual differences lead to variations in outcome regarding these functions after treatment. In some cases the patient has to continue life with an impaired communication and a changed eating function. If the laryngeal tumor is large or when a tumor recurs despite treatment, surgical removal of the larynx, a *laryngectomy* is performed. A laryngectomy affects the patient's physical as well as the psychological well-being. The laryngeal voice is lost, the breathing pattern is changed, and many laryngectomees also find it difficult to eat and socialize as they used to.

As a speech-language pathologist working with rehabilitation of laryngectomees, questions about the volitional control of the new voice source and speech strategies after laryngectomy have often come up. Many laryngectomees are able to speak fluently within a month after surgery while others struggle during long periods without gaining a functional speech. From a clinical point of view, it is important to seek answers to how the communication abilities may be improved for laryngectomees. This thesis aims to contribute to knowledge and understanding of the voice and speech functions and the life situation of laryngectomees.

## 1.1 LARYNGEAL CANCER

### **Etiology, epidemiology, and prognosis**

Anyone can develop laryngeal cancer, although the main causative factor is tobacco use. High alcohol consumption may also contribute, and a combination of cigarette smoking and alcohol consumption has an additive effect to the risk factor (Ramroth et al 2004). Dust from cement and asbestos, gasoline, diesel fuel and other chemical fumes affect the mucosa in the aero digestive tract, and long periods of exposure to this kind of environmental pollution are also contributors to a high risk of developing laryngeal tumors (Dietz et al 2004; Purdue et al 2006). In studies focusing on risk factors for laryngeal cancer it has been shown that also gastroesophageal reflux disease (GERD) is a causative factor (Qadeer et al 2005; Vaezi et al 2006).

The incidence of laryngeal cancer varies among countries and parts of the world. The incidence rate is high in the Mediterranean countries for example in Spain, France, and Italy; in central and eastern European countries for example in Poland, Croatia, and Slovakia; and in the United States in the black population. Laryngeal cancer is most commonly found in men, and in the male population of these countries the incidence rate is above 10 per 100,000 individuals (Parkin et al 2002). However, in Sweden laryngeal cancer is relatively rare. In 2006, laryngeal cancer constituted 0.3 % of all cancer in Sweden (Socialstyrelsen 2007). Since the beginning of the 21<sup>st</sup> century, the incidence rate has been about 4 individuals per 100,000, and the rate has steadily decreased from 1970. The decrease in laryngeal cancer is especially noticeable in men but is still six times more common in men compared to women (Cancerfonden 2005).

The prognosis for laryngeal cancer is relatively good dependent on the subsite of the tumor and the stage, i.e. extent of the disease. In Sweden the five year survival rate after treatment for a small tumor on one vocal fold is about 90-95%. The five year survival rate for all laryngeal cancer is about 66 % (Socialstyrelsen 2007).

## Clinical symptoms and diagnosis

The most common location for laryngeal cancer is on the vocal folds (glottic), on one or both of the folds. Tumors can also be supraglottic, i.e. be located in the cavities above the vocal folds and/or on the epiglottis. Tumors located below the glottis, subglottic tumors, are less common.

The symptoms of laryngeal cancer depend on the tumor's location and size. A small *glottic* tumor often affects the voice and can cause persistent hoarseness. Therefore, a glottic tumor can often be diagnosed at an early stage. Advanced glottic tumors give rise to symptoms like persistent cough, cough mingled with blood (hemoptysis), and stridor due to airway obstruction. An early staged *supraglottic* tumor typically causes non-specific symptoms such as for example diffuse pain and slight dysphagia. As the tumor progresses, the dysphagia increases, and ear pain (otalgia) can occur as well as pain at a tumor-specific location. Due to the initial non-specific symptoms, individuals with supraglottic tumors often have a regional node metastasis and/or a more advanced local disease at diagnosis. The first symptoms of a *subglottic* tumor are often dyspnea and hemoptysis. The individual may also get a persistent hoarseness in cases in which the tumor has spread superiorly to the glottis or affected the recurrent laryngeal nerve laterally.

Individuals with suspected laryngeal cancer are submitted to a microlaryngoscopy which is performed under general anesthesia. During this laryngoscopy, the extent of the tumor at the primary site is defined and a biopsy for histopathological anatomical diagnosis (PAD) is taken. Most tumors are squamous cell carcinomas. Adenoid cystic carcinoma and sarcoma may also occur, but these cancers are rare in the larynx. In order to correctly stage the tumor most patients will also undergo a computer tomography (CT) from base of skull, neck and thorax, a magnetic resonance imaging (MRI), and an ultrasound guided fine needle aspiration cytology (FNAC). The aim with these procedures is to classify the size and extent of the primary tumor (T). Furthermore, any spread to regional lymph nodes (N) and/or possible distant metastases (M) are located. Laryngeal tumors are staged from I to IV according to the TNM-classification (Sobin and Wittekind 2002).

## Treatment

Treatment for laryngeal cancer varies considerably over the world and may depend on whether the individual sees a medical oncologist or a surgeon at the first medical consultation. In the Nordic countries radiotherapy is a commonly used treatment. The extent of treatment depends on location, stage and resectability of the tumor. The treatment regimen is also dependent on the individual's physical and functional condition and his/her own desire for treatment modality, and such considerations can lead to a more individualized treatment.

### *Radiotherapy*

The treatment regimen in Sweden for laryngeal cancer is mainly oncological, with radiotherapy as the first choice. The goal is to both cure the patient and to preserve the larynx, if possible.

The radiotherapy treatment for laryngeal cancer is usually given in a conventional fractionated regimen with a daily dose of 2 Gy (5 days/week) until full dose (66-70 Gy)

is reached after 6 to 7 weeks. An alternative is hyperfractionated radiotherapy, with two fractions per day (lower doses) but with the same length of treatment period. There is also a third regimen, accelerated radiation, in which the patient gets several doses per day during a shorter treatment period, resulting in higher daily doses compared to the conventionally fractionated regimen. The neck area with the lymph nodes is included in the target field if the disease has spread to the lymph nodes, although given a lower radiation dose of 40-50 Gy.

Compared to surgery, radiotherapy stretches over a relatively long time. Common acute side-effects are dry mouth, mucositis, dysphonia/aphonia, dysphagia, and skin reactions. These side-effects are dependent on target volumes, radiation doses and individual sensitivity, and usually decline after a period of time. Late side-effects, as persistent dysphonia and dysphagia, may also occur. Such side-effects are often due to fragility in the tissues post radiation, and fibrosis within the pharynx and larynx.

### *Chemotherapy*

Chemotherapy is used as an additional treatment for head and neck cancer. Several studies have evaluated chemotherapy treatment regimes. In a study of laryngeal cancer, comparing radiation treatment with concomitant chemoradiotherapy, it was shown that laryngectomy could be avoided to a higher extent in the group who had received chemoradiotherapy compared to the group that had received only radiation (Forastiere et al 2003). A meta-analysis of head and neck cancer, comparing chemotherapy followed by radiotherapy with concomitant chemoradiotherapy, showed slightly better survival rates in the group who got chemoradiotherapy than in the group who started with chemotherapy, followed by radiotherapy (Pignon et al 2007). However, treatment with chemotherapy for laryngeal cancer is not yet used routinely at oncological clinics in Sweden.

Chemotherapy is a treatment that can involve life threatening side-effects because the toxin affects the whole body. The toxins can also increase the risk of developing other forms of cancer and these risks must be taken into consideration in decisions for treatment.

### *Surgery*

Surgical resections of early staged laryngeal tumors aims to cure the patient and at the same time preserve as much of the larynx as possible. These surgical procedures are alternative treatment to radiotherapy.

Resections of small (T1N0) glottic tumors, limited to one vocal fold, can be done with the use of endoscopic transoral CO<sub>2</sub> laser (Steiner 1993; Rydell et al 1995). The benefits of this surgery include reduced treatment time and side effects as well as lower costs. Cordectomy is another method that can be used for patients with T1/T2 glottic tumors. However, this procedure is often more negative for the voice production compared to laser surgery and radiotherapy. Partial laryngectomy (vertical, supracricoid or supraglottic) can be an alternative to total laryngectomy. These surgical procedures preserve parts of the larynx and allow patients to continue breathing normally through nose and mouth. However, both the voice and swallowing functions are often affected negatively. For these procedures it is also important that the patient has a good pulmonary function prior to the surgery because of the increased risk for aspiration during food intake. Neck dissection is needed in addition to the cordectomy or the partial laryngectomy if the cancer has spread to the regional lymph nodes.

Large laryngeal tumors are treated with radiotherapy as first choice. If local control cannot be obtained or if the tumor recurs at a later stage, total laryngectomy may be the only treatment option. A stage IV laryngeal tumor is often treated with laryngectomy first, especially if the tumor affects the breathing. The surgery is then followed by postoperative radiotherapy if needed. In Sweden, approximately 50 patients per year are treated with total laryngectomy due to their laryngeal cancer.

## 1.2 TOTAL LARYNGECTOMY

A total laryngectomy means that the entire larynx, the hyoid bone, and the strap muscles of the anterior neck are removed. A common routine is to also remove at least half, and sometimes the entire thyroid gland as well as regional neck nodes. The trachea is incised between the second and third tracheal ring, or lower if the tumor extends subglottically, and the trachea is sutured to the anterior neck wall to create a permanent tracheostoma.

When adequate pharyngeal mucosa is present after the removal of the larynx, the pharynx is closed to form a neopharynx. If the tumor extends into the hypopharyngeal area, the larynx as well as the affected part of the hypopharynx is removed. In these cases a reconstruction with the use of a free tissue flap may be necessary. Before closure of the pharyngeal mucosa, the tension of the upper esophageal sphincter is controlled by palpation, and frequently a myotomy is performed.

In Sweden, a primary tracheoesophageal (TE) puncture is nowadays most often made at the time of laryngectomy, and a voice prosthesis is placed in the fistula for future vocalization. Different voice prostheses have been in use in Sweden throughout the years, and the most common during the 1980-ies and early 1990-ies were the Blom-Singer voice prostheses (Singer and Blom 1980; Perry 1988). Today, Provox 2<sup>®</sup> voice prosthesis is the most widely used (Ackerstaff et al 1999). A more elaborative description of the surgical procedure and the creating of a TE-fistula can be found in Hilgers (1995).

After the surgery, the laryngectomee commonly stays over night in the intensive care with drains in the neck to help reduce the swelling and a cannula placed in the tracheostoma. Antibiotics are given, as well as medical prophylaxis to avoid thrombosis. Serum calcium and thyroid hormone levels are checked due to the diminished or absent thyroid gland. Nutrition is initially given parenterally and thereafter through a nasogastric feeding tube since no normal drinking or eating is allowed. Oral communication is not possible and the laryngectomee may only use written messages and body language. The reflex to cough and sneeze is intact, but the produced mucus is discharged from the tracheostoma and not from the mouth and nose. It should be noted that all these changes might be a frightening experience for the individual, although he/she has been given preoperative information about this situation. During the hospital stay, which lasts for about 2-3 weeks, much of the swelling of the neck disappears. The drains are removed after a few days but the feeding tube stays in place until the wounds have healed. Unless spontaneous fistulas or other infections that could affect the healing occur, a period of 10-14 days is needed for the wounds to heal. After this period, the laryngectomee is allowed to start drinking and eating normally, and the first attempt to phonate with the esophageal voice source is made. The most obvious long-term effects of a laryngectomy are a changed breathing pattern and a loss of the laryngeal voice source. Indirect changes of the new breathing

pattern are the negatively affected smell and taste, decreased lung capacity, and a difficulty to carry heavy things.

### Communication after total laryngectomy

A laryngectomee with preserved anatomical structures for articulation and resonance has two ways of activating the new voice source, the pharyngo-esophageal (PE) segment (see section 1.3). The traditional way, still in use in many countries, is the *esophageal (E) speech*. E-speech is produced by insufflation of air into the esophagus, followed by a controlled egress of air that will make the PE-segment vibrate (Figure 1a). Insufflation of air can be done either by injection or inhalation. In learning the *injection technique*, the laryngectomee is instructed to increase the oropharyngeal air pressure, for example during the production of a stop consonant. The increased oral pressure overcomes the resistance of the PE-segment and forces the esophagus to open. The *inhalation technique* for air intake uses the physiological effect of inhalation, during which the thoracic air pressure decreases below the environmental air pressure. The negative pressure below the level of the PE-segment is increased and air is sucked into the esophagus. In both techniques, the air has to be quickly redirected to start the vibrations in the PE-segment for phonation. Proficient E-speakers often use a mix of both techniques for air intake. E-speech is demanding in terms of length of the treatment, since it typically takes 6 to 12 months in speech therapy for the laryngectomee to acquire fluent speech. However, after this therapy period the E-speaker seldom needs further speech rehabilitative actions.

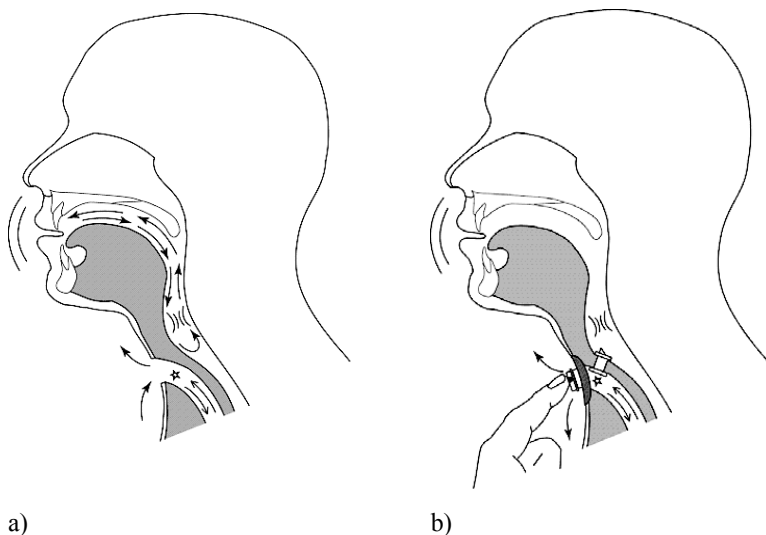


Illustration: Lena Lyons, Studentlitteratur

**Figure 1.** Schematic picture of a) esophageal speech and b) tracheoesophageal speech.

*Tracheoesophageal (TE) speech* is the alternative way of activating the PE-segment for speech. TE-speech is produced by use of a voice prosthesis situated in a fistula, which is created surgically in the wall between the trachea and the esophagus. The fistula puncture is usually made primarily at the time of laryngectomy, but it can



also be made secondarily some weeks or months after the laryngectomy. The voice prosthesis functions as a one-way valve, allowing air from the lungs to pass into the esophagus, without that food and liquids pass into the trachea. When the laryngectomee digitally occludes the tracheostoma, the air from the lungs is directed through the prosthesis into the esophagus beneath the PE-segment, for phonation (Figure 1b). A great advantage with TE-speech is that for most laryngectomees voice restoration occurs within 2-4 weeks postoperatively. A disadvantage is that the speaker needs to clear out the prosthesis from mucus, often several times a day, to maintain a good function. Furthermore, the prosthesis has to be replaced 2-4 times per year (or more often, depending on individual variation) when the valve is malfunctioning and causes aspiration of liquids.

In the interest of gaining a better lung function as well as better hygiene and protection of the tracheostoma, stoma devices with heat and moisture exchange (HME), have been developed. These stoma devices can be used by any laryngectomee, regardless of speaking technique. The stoma devices have been shown to improve both speech and respiratory function in TE-speech (Hilgers et al 1991). Hands-free tracheostoma valves with HME are also available for TE-speakers (Lorenz et al 2007), allowing the speaker to produce voice without manual control.

An artificial voice source, i.e. an electrolarynx, can be used as a complementary voice source for a laryngectomee, for example in noisy surroundings and during meals. For laryngectomees who are not able to use a physical voice, but have an intact articulatory capacity, *electrolaryngeal (EL) speech* is often the first choice for communication.

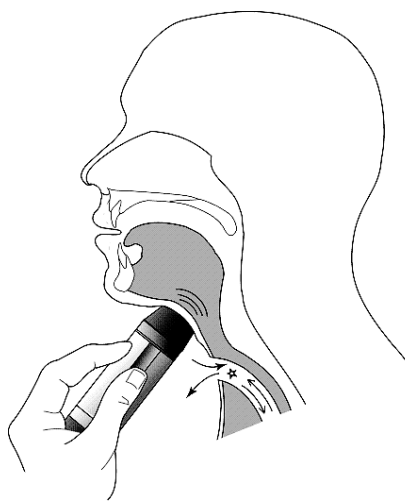


Illustration: Lena Lyons, Studentlitteratur

**Figure 2.** Schematic picture of electrolaryngeal (EL) speech

An electrolarynx is preferably held against the neck side (Figure 2). The vibrations, transferred from the apparatus into the pharynx and the mouth, carry the articulatory movements to form an audible and intelligible speech.

One disadvantage with EL-speech is that it is monotonous ('mechanical') and demands manual control. However, ongoing research on voice-related neural signals for hands-free electrolarynx control shows promising results (Heaton et al 2004).

In case the esophageal voice source and the articulation have been very negatively affected from the cancer treatment, the laryngectomee may use technical communication aids that are based on writing, sometimes in conjunction with synthetic speech.

### 1.3 THE PHARYNGO-ESOPHAGEAL SEGMENT

The transitional area between the pharynx and the most upper part of the esophagus constitutes the place of the voice source in both E- and TE-speech. This area is called the pharyngo-esophageal (PE) segment. The PE-segment is sometimes used synonymously with the upper esophageal sphincter (UES). In the literature, the terms 'pseudoglottis' (false or artificial glottis), and 'neoglottis' (a new form of glottis) are also used for the alaryngeal voice source. Throughout this thesis, the physical voice source of a laryngectomee will be called the PE-segment.

The morphology and the placement of the PE-segment vary from one laryngectomee to another, and its' location changes also during phonation and swallowing (Diedrich and Youngstrom 1966; Damsté and Lerman 1969; Van As et al 2001). The anatomical definition for the morphology is that the PE-segment is a protrusion from the posterior (alt. dorsal) and/or anterior (alt. ventral) wall in the lower pharynx. Lateral walls of the pharynx may also contribute to the shape of the PE-segment. Sometimes more metaphorical descriptions are used for the shape of the PE-segment, for example "egg-shaped" or "bulky". The placement of the segment is specified in relation to the cervical (C) column and can vary depending on the individual's anatomical disposition and on pitch and intensity. Diedrich and Youngstrom (1966) found PE-segment levels from C3 to C7 in E-speakers, and their results have been confirmed by several other studies of both E-speakers and TE-speakers (Isman and O'Brien 1992; Van Weissenbruch et al 2000; Van As et al 2001; Lundström et al 2008).

The musculature in the PE-segment consists mainly of the lower pharyngeal constrictor muscle and the cricopharyngeal muscle. In electromyographic (EMG) studies of the PE-area it has been found that many laryngectomees have two "bulges", one consisting of the thyropharyngeal muscle and the other of the cricopharyngeal muscle, and that the voice source mainly consists of the thyropharyngeal part (Omori et al 1994). Regardless of one or two bulges, the pharyngeal musculature is innervated by the pharyngeal plexus, which consists of both the glossopharyngeus nerve (IX) and the vagus nerve (X).

Investigation of the anatomy and the physiology of the PE-segment can be made in different ways. Radiological studies have been made for many years (Vrticka and Svoboda 1961; Diedrich and Youngstrom 1966; Damsté and Lerman 1969; Bentzén et al 1976). Diedrich and Youngstrom (1966) made a thorough radiological study of twenty E-speakers. The results of this study provided fundamental knowledge about the shape and placement of the PE-segment as well as of changes in the anatomical structures surrounding the segment. *Videoradiographic* investigations during the past twenty years, documenting the dynamic movements in the pharyngo-esophageal area, have further increased our knowledge about the PE-segment. A major contribution were made from videoradiographical studies by Cheesman et al (1986) and McIvor et

al (1990) who provided a classification of degree of tonicity in the PE-segment in relation to voice function. Their classification led to the introduction of myotomy for avoidance of a spastic or hypertonic PE-segment. Another contribution was made by Van As et al (2001) who developed a protocol for videoradiographical assessment including quantitative measurements of the PE-segment. Some of the findings of their study were that measured size and closure pattern of the segment showed significant relationships with tonicity.

The vibratory pattern in the PE-segment is mostly irregular and highly varied. Investigation of vibrations in the alaryngeal voice source is therefore difficult to make by means of *stroboscopy* since this method is frequency-dependent. In some studies stroboscopy is claimed to be a useful tool in examining the PE-segment (Dworkin et al 1998; Dworkin et al 1999; Omori and Kojima 1999). A frequency-independent instrument, such as *high-speed imaging*, allows for examination of all kinds of phonation regardless of speech proficiency and degree of aperiodicity in vibrations (Eysholdt et al 1996). High-speed imaging has therefore been used in several studies of the vibratory pattern in the PE-segment (Van As et al 1999; Lundström and Hammarberg 2004; Saito et al 2006; Jongmanns et al 2006).

The above-mentioned techniques for investigations of the PE-segment are all examples of invasive techniques. These techniques mostly require medical expertise, for example a radiologist or a phoniatician, although some SLPs are trained in doing nasofiberoendoscopy. A non-invasive technique that can be used by any SLP is *electroglottography*. Saito et al (2006) and Kazi et al (2007b and 2008) used electroglottography for analyses of the PE-segment in TE-speakers. The results of these studies reported reliable electroglottographical data about the vibratory pattern in the PE-segment.

#### 1.4 PERCEPTUAL ANALYSES OF LARYNGECTOMEE SPEECH

Compared to laryngeal voice, the voice of most laryngectomees sounds deviant. The thicker and more irregular mucosa covering the PE-segment gives aperiodic and often chaotic vibrations and as a consequence a rough voice quality and a low pitch. Laryngectomee speakers are perceived as intelligible by most listeners when using running speech, although their voice quality, pitch and articulation might be perceived as deviant. However, in utterances of single words or syllables, the precision in the speaker's articulation as well as phonation is more demanding. Previous studies have shown that E-speakers and TE-speakers score lower on intelligibility test compared to laryngeal speakers (Doyle et al 1988; Hammarberg et al 1990). Doyle et al (1988) found that the E- and TE-speakers were similarly intelligible in their overall production of voiced and voiceless consonants, but that the TE-speakers were perceived to produce voiced consonants better than the E-speakers.

In some studies perceptual evaluation of voice quality in laryngectomees has been assessed with scale categories such as 'good', 'fair/reasonable' and 'poor' (Bentzen et al 1976; Van As et al 2001; Op de Coul et al 2003). The rating scale GRBAS (Hirano 1981), comprising Grade of aberrant voice quality, Roughness, Breathiness, Asthenicity and Strain has been widely used in studies of various laryngeal voice disorders. The parameters are rated on a four-point scale. In studies including perceptual assessments of partially and totally laryngectomized speakers, results from GRBAS-ratings have shown that not all five parameters seem to be reproducible and

reliable for TE-speech (Kazi et al 2007b; Torrejano and Guimarães 2008; Singh et al 2008). Best results have been shown for the parameters grade and roughness. Furthermore, the four-point scale has been found not sensitive enough for differentiation between voice qualities in partially and totally laryngectomized speakers (Singh et al 2008).

Bipolar semantic scales are commonly used in the Netherlands for perceptual assessment of laryngeal as well as alaryngeal speech, for example 'deviant-normal', 'unpleasant-pleasant', 'ugly-beautiful' (Verdonck-de Leeuw 1998; Van As 2001; Jongmanns 2008). The studies include a various amount of semantic scales, covering pitch, voice quality, temporal aspects and intelligibility.

Direct magnitude estimation (DME) has been used in ratings of TE-speech. The parameters used in these studies attribute a broader aspect of speech: acceptability, voice pleasantness, naturalness and overall severity (Eadie and Doyle 2002 and 2005). Comparisons were made between ratings on the magnitude scale DME and ratings made on equal-appearing interval scales (EAIS). The results gave support for the use of DME, with the exception for the parameter of 'naturalness', for which there was no difference in validity between DME and EAIS.

Yiu and Ng (2004) compared EAIS and the Visual Analogue Scale (VAS), another magnitude scale, for perceptual evaluation of voice quality in dysphonic and normal laryngeal speech. Since VAS uses a continuing line, typically 10 cm long, Yiu and Ng used EAIS with 11 intervals placed out on a 10 cm-line to make the two scales have the same length. They found a linear relationship between the EAIS and VAS for the perceptual judgments of roughness and breathiness, suggesting that the psychoperceptual characteristics of these two parameters could be described equally well by the two scales.

Visual analogue scales are commonly used in Sweden for assessment of voice quality in laryngeal speakers (Hammarberg 2000; Södersten et al 2005; Schalling et al 2007). In this investigation, perceptual assessment of voice quality and speech has been made with the use of VAS. Assessments have been made partly with the computer-based program VISOR (Granqvist 2003), see section 2.4, and partly with assessment protocols on paper.

## 1.5 ACOUSTICAL ANALYSES OF LARYNGECTOMEE SPEECH

Acoustical measurements of voice often include frequency and amplitude analyses of the acoustic waveform. Temporal measurements such as speaking rate, phrase length and pause time during reading and in spontaneous speech also provide important information about the speaker's ability to coordinate breathing and phonation. Previous studies of laryngectomee speech have focused on the mentioned acoustical measures, and on acoustical differences and similarities that might exist between TE-speech, E-speech, and laryngeal speech. In Table 1, examples of studies investigating fundamental frequency, voice intensity and speaking rate are listed.

The main difference between E-speech and TE-speech is the amount of phonatory air the speaker can use, and the way the air enters into the esophagus. The difference in phonatory air leads to a lower vocal intensity, a slower reading rate and shorter phrase length in E-speakers compared to TE-speakers and normal laryngeal speakers.

Measurements of perturbation depend highly on accurate frequency and voice intensity tracking in the voice signal and it is therefore important that the computer based programs allow for adjustments and corrections in the analysis of fundamental frequency (F0). In studies of F0-perturbation (jitter) and voice intensity perturbation (shimmer) in laryngectomee speech, higher perturbation values are reported for E-speakers compared to TE-speakers (Robbins et al 1984), and for TE-speakers compared to laryngeal speakers (Van As 2001; Singh et al 2008).

**Table 1.** Examples of studies with acoustical analyses of male laryngectomee speech.

Study	Subjects	Fundamental frequency Mean F0 (Hz)	Voice Intensity Mean SPL (dB)	Speaking rate wpm
Blood (1984)	10 TE	88	82	
	10 E	65	70	
	10 L	121	84	
Robbins et al (1984)	15 TE	102	79	127
	15 E	77	59	99
	15 L	103	69	173
Pindzola & Cain (1989)	5 TE			152
	5 E			94
	15 L			159
Max et al (1996)	10 TE		71	
	10 E		62	
Hillman et al (1998)	21 TE			192
	5 E			121
	30 EL			161
Van As et al (2001)	21 TE	115		
	20 L	111		
Lundström and Hammarberg (2008)	5 TE	111	67 (Leq dB)	
	4 E	108	60 (Leq dB)	
Lundström and Hammarberg (2009)	35 TE	109	69 (Leq dB)	131

NOTE: TE – tracheoesophageal speech; E – esophageal speech; EL – electrolaryngeal speech; L - laryngeal speech, wpm – words per minute.

Results from studies of the voicing distinction in both E- and TE-speakers (Christensen et al 1978; Connor et al 1985; Robbins et al 1986; Doyle et al 1988; Hirose 1996; Saito et al 2000; Searl and Ousley 2004) have shown that the perception of voiced and voiceless consonants, especially stop sounds, is dependent on the speaker's ability to make differences in closure duration (stop gap), voice onset time (VOT), and in intra oral pressure. In laryngeal speech the closure duration and VOT is usually longer for voiceless stops compared to voiced stops. Voiceless stop consonants

(p, t, k) are produced with an open glottis during the oral closure of the stop. When the articulatory stop is released it allows the air from the lungs to flow into the vocal tract, generating aspiration instead of phonation. For the voiced stops (b, d, g) the glottis is closed during the oral closure and at the moment of stop release the air forces the vocal folds into vibration, thus carrying phonation into the vocal tract. Thus, the ability to make differences between voiced and voiceless speech sounds is determined by physiological patterns, which are reflected in the acoustical measures of closure duration and VOT. In the study by Saito et al (2000), audio-perceptual intelligibility tests, measurements of VOT and closure duration of voiced and voiceless intervocalic stop consonant /b/ and /p/ were made in 40 TE-speakers. The results from this study showed that speakers who were regarded as highly intelligible had both longer VOT and longer closure duration in the voiceless stop consonant than in the voiced cognate.

## 1.6 QUALITY OF LIFE AFTER LARYNGECTOMY

‘Quality of life’ is a subjective concept that changes throughout life. Health-related quality of life (HRQL) is a multi-dimensional concept that refers to an individual’s well-being. HRQL has to do with aspects relevant to physical health, psychosocial status, social life and level of autonomy. When changes in health occur, several life aspects are affected, and as a consequence the overall individual quality of life is changed.

The most common way to investigate HRQL is by use of questionnaires. A well-known questionnaire is the Medical Outcomes Short Form 36-item, SF-36 (Ware and Sherbourne 1992), translated and validated into many languages, among them Swedish (Sullivan et al 1995). The SF-36 includes questions about physical limitations and their effect on daily activities and work, and questions about pain, fatigue, and mental health. Overall judgments of present and predicted health status are also included. The SF-36 is a questionnaire suitable for different types of patients and problems, and has been used in studies of HRQL in laryngectomees (Stewart et al 1998; Armstrong et al 2001; Schuster et al 2003).

Cancer-specific HRQL-questionnaires, for example the Functional Assessment of Cancer Therapy – General, FACT-G (Cella et al 1993), and the questionnaire from the European Organization for Research and Treatment of Cancer (EORTC), EORTC QLQ-C30 (Aaronson et al 1993), have been developed. The main purpose of cancer-specific questionnaires is to gain knowledge about the patient’s well-being before, during and after treatment for cancer. Although the FACT-G and the EORTC QLQ-C30 are cancer-specific, problems due to specific tumor locations are not fully captured. Therefore, tumor-specific questionnaires for cancer patients have also been developed, for example the FACT – Head and neck, FACT H&N (List et al 1996), and the EORTC QLQ-H&N35 (Bjordal et al 1999 and 2000). These tumor-specific questionnaires are often used in conjunction with the general or core questionnaire.

Studies of HRQL in head and neck cancer-patients include data from laryngeal cancer patients. Previous prospective Scandinavian studies of patients treated for head and neck cancer used the EORTC-questionnaires (Bjordal et al 2001; Hammerlid et al 2001 a b; Nordgren et al 2003). Radiotherapy was given as the first choice treatment and at follow-up only a few of the patients with laryngeal cancer had been treated with surgery, i.e. laryngectomy. Results from these studies regarding HRQL in laryngectomees are therefore sparse.

## 1.7 AIMS

The overall aim of the study was to investigate the voice function, the voice handicap, and the health-related life quality in laryngectomees.

Specific aims were to:

- Describe and measure anatomical and physiological characteristics of the voice source, the pharyngo-esophageal segment in laryngectomees
- Investigate possible relations between the characteristics of the pharyngo-esophageal segment, perceptual assessments and acoustical measures of the voice and speech function in laryngectomees
- Investigate how laryngectomees judge their voice handicap and health-related quality of life, and how the voice handicap relates to other aspects of health
- Investigate how laryngectomees' self-reported voice handicap relates to perceptual assessments and acoustical measurements of speech and voice.

## 2 METHODS

### 2.1 PARTICIPANTS

Fifty-four individuals, who had undergone laryngectomy, participated in all of the four studies. The individuals were invited to participate by their SLP (study I and II) or by a letter of invitation sent from the ENT-clinic at Karolinska University Hospital (study III and IV).

Table 2 summarizes information on the participants' speaking technique and gender, and the number of participants in each study. Two laryngectomees participated in both study I and II. In study III there were 43 participants, and 35 of them were included in study IV. Speaking technique varied between the participants although the predominant technique was TE-speech.

**Table 2.** Speaking technique, gender, and number of participants in the four studies. M=male, F=female.

Speaking technique	Study I	Study II	Study III	Study IV
Tracheoesophageal speech	3 M	4 M, 1 F	36 M, 2 F	35 M
Esophageal speech	1 M	3 M, 1 F		
Electrolaryngeal speech			4 M, 1 F	
Total	4	9	43	35

The four male participants in study I had a mean age of 59 years (range 54 to 69 years) at the time of investigation. Length of postoperative period varied from 3 to 15 years. The participants had been preoperatively treated with radiotherapy and had undergone a standard laryngectomy. Three of them had also undergone a neck dissection.

Nine laryngectomees participated in study II, seven males and two females. Their mean age at the time of investigation was 63 years (range 52 to 72 years). Mean time since laryngectomy was 8 years (range 2 to 23 years). All but the female E-speaker had undergone preoperative radiotherapeutic treatment.

In study III, forty men and three women participated. Their mean age was 68 years (range 48 to 84 years) and mean follow-up time was 4.5 years (range 6 months to 12 years). Thirty-two participants received preoperative radiotherapy, eight were given postoperative radiotherapy, while three participants had not received any radiotherapy. Thirty-eight participants used tracheoesophageal (TE) speech as their main way of communication. Of the five participants using electrolarynx for communication, two had undergone more extensive surgery including free flap reconstruction. For the remaining three, the use of an esophageal voice source was severely restricted due to constrictions in the pharyngo-esophageal area.

In study IV, thirty-five male TE-speakers were included. Their mean age at the time of the investigation was 69 years (range 48 to 84 years) and mean length of the postoperative period was 4;8 years (range 6 months to 12 years). Thirty-two participants with laryngeal tumors had undergone a standard laryngectomy. The three participants with a hypopharyngeal and/or oropharyngeal tumor site had undergone



surgery including reconstruction of the pharynx with a free flap. Two of these participants had an affected tongue base due to the reconstruction surgical procedure.

## 2.2 SPEECH SAMPLES AND RECORDING PROCEDURES

Speech samples included syllable repetitions, utterances of one-syllable words, and reading of paragraphs. For details about different speech tasks, analyses and measurements derived, see Table 3. More specific information about the analyses is given in section 2.3, 2.4, and 2.5.

**Table 3.** Speech tasks, types of analyses and measures in study I, II and IV.

Study material	Analysis	Measure	Study
Syllable repetitions	Anatomical/ physiological	Shape of PE-segment Vibratory locus in PE-segment Mucosal wave in PE-segment Regularity in vibratory pattern Open-closed phase Vibratory pattern related to voiced-voiceless phoneme	I
	Perceptual	Categorical judgment of plosives	I
	Acoustical	Voice Onset Time (VOT) Closure duration	I
Paragraph reading, one-syllable words	Anatomical/ physiological	Size (surface) of PE-segment Prominence of PE-segment Distance between PE-segment and the anterior pharyngeal wall Maximal width beneath PE-segment Location of PE-segment in relation to cervical column	II
Paragraph reading	Perceptual	VAS ratings of voice quality Development of protocol for perceptual analyses of speech and voice	II IV
	Acoustical	Mean fundamental frequency Mode fundamental frequency Voice intensity, Leq Speaking rate Articulation rate Phrase length Number of pauses Percent pause time	II, IV IV II, IV IV IV IV IV IV

Audio-recordings of the speech material and high-speed imaging recordings (study I) were made simultaneously in an ordinary medical examination room. A microphone (Audio Technica ATM31) was used with a mouth-to-microphone-distance of 30 cm.

The audio-recordings together with the triggering signal from the high-speed equipment were made in the Soundswell program (Ternström 2000) and stored directly in the computer.

The audio-recordings in study II were made simultaneously with the VRG-recordings. In addition to these audio-recordings, the nine laryngectomees were also recorded in a sound-treated booth while reading a Swedish standard paragraph. An electret-condenser microphone was used, positioned and mounted on a head-set to ensure a constant mouth-to-microphone distance of 15 cm. The recordings in study II were made on Digital Audio Tapes (DAT) and transferred to a computer for further analysis thereafter.

In study IV, the recordings of the same reading paragraph as in study II were made in a sound-treated booth using the Soundswell program. As in study II, an electret-condenser microphone mounted on a head-set was used, with a mouth-to-microphone distance of 15 cm. The recorded voice signals were stored directly in a computerized database.

### 2.3 ANALYSES OF THE PE-SEGMENT

Analyses of the PE-segment were made in study I and II.

In study I, *high-speed imaging recordings* of the PE-segment was made. The PE-segment was examined from above with the use of a flexible endoscope (Olympus ENF, P3) with an extra channel for suction of mucus, and was connected to a high-speed camera (KODAK Ektapro high-speed video system, or Weinberger SpeedCam +500). Before recording, the laryngectomee was asked to drink some water to eliminate as much mucus as possible. Occasionally the suction channel in the fiberscope was used if mucus was still covering the entrance of the esophagus.

The four speakers, one E-speaker and three TE-speakers, were asked to repeat VCV syllables including medial voiced or voiceless stop sounds [p/b, t/d, k/g] surrounded by [i:] vowels. Repeated trials were made for each syllable, because it was sometimes difficult to make good recordings.

As an initial part of the evaluation of the high-speed images, an analysis of the general characteristics of the PE-segment was made by use of the following parameters: 1) shape of the PE-segment, 2) location of vibration, 3) mucosal wave, 4) regularity of vibration, and 5) relation open-closed phase (Van As et al 1999). These parameters inform about the appearance and movements in the voice source as well as of the overall closing pattern and vibratory behaviour.

The second part of the evaluation was a detailed frame-by-frame analysis of the high-speed images by use of the program High-Speed Tool Box (Larsson et al 2000), in which the images are simultaneously linked to the sound signal by means of a triggering signal. Focus in these frame-by-frame studies was to evaluate the speakers' ability to interrupt the vibrations and make an opening gesture in the PE-segment during a voiceless stop consonant.

*Videoradiography (VRG)* was used for investigations of the PE-segment in study II. Nine laryngectomees participated, five TE-speakers and four E-speakers. The fluoroscopic field included the mouth, the pharynx and the esophagus down to the level of the clavicle. Prior to the VRG the speakers swallowed a dose of about 10

milliliter of Barium contrast (Mixobar High Density) to visualize the walls in the pharynx and the esophagus. Although recordings were made in both frontal and lateral view, analyses could only be made of the lateral projections due to the position of the chin, which in several of the participants partly or totally covered the activity in the hypopharynx.

Recordings with a rate of 25 pictures per second were made during both phonation and silence. Recordings were also made when the participants had a soft transparent ruler placed on their necks, showing a reference scale in millimeters to enable quantitative measurements.

The VRG-recording (lateral projections) of each participant was analysed with regard to the placement of the PE-segment in relation to the vertebrae in the cervical column, and quantitatively by use of metrical measurements according to Van As et al (2001). The following metrical measurements were made: 1) Prominence (PROM) of the segment, where the measurement line was placed perpendicular to the posterior wall at the most prominent place of the PE-segment, 2) Minimal distance (MIN) between the edge of the PE-segment and the anterior wall, 3) Maximal distance (MAX) below the PE-segment between the anterior and posterior esophageal walls, 4) Surface area (SUR) of the PE-segment (see Study II, figure 1).

All measurements were made on three frames depicting vowel phonation in three one-syllable words, and two frames depicting silence/rest position. The frames were digitized with a frame grabber and saved as image files in the program Adobe Premiere 6.0. Distances were measured in pixels and calibrations were made, changing pixels into mm. For PROM, MIN and MAX the measurements were made in (mm), for SUR the measurements were made in (mm<sup>2</sup>).

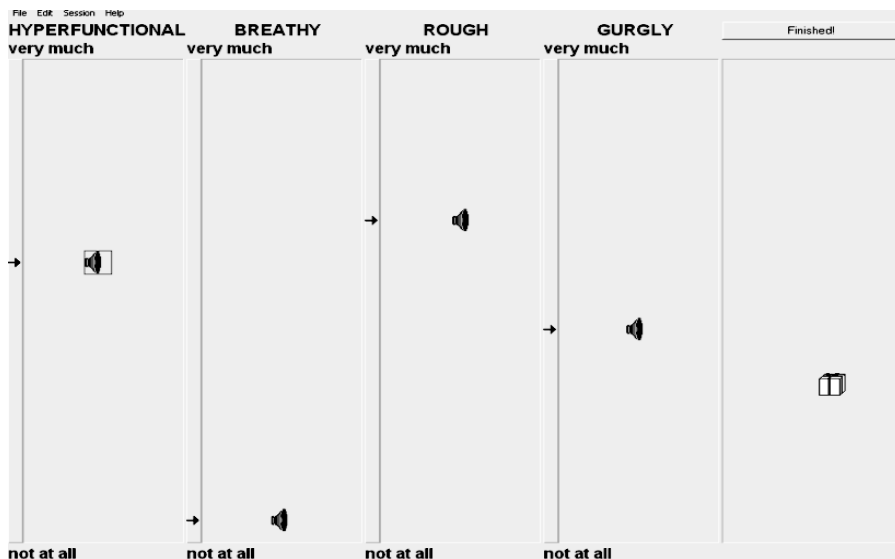
## 2.4 PERCEPTUAL ANALYSES

Perceptual analyses of speech and voice were performed in study I, II and IV.

In study I and II the interactive computer-program VISOR (Granqvist 2003) was used for audio-perceptual analyses. In this program the scales (columns) are vertically placed on the computer screen and are meant to be used as visual analogue scales (Figure 3). However, the program can also be used for categorical judgments only, placing samples in labeled columns. The VISOR program allows the listeners to hear each voice sample as many times as wanted. Another advantage is that the program calculates each listener's judgments of the parameters. The scale in VISOR is 0-1000, with 0 meaning 'zero', i.e. absence of that particular parameter, and 1000 meaning 'high degree of'. The judged values are automatically saved in text-files which thereafter can be used for further analyses. Judgments/ratings are made individually.

*Categorical perceptual judgments* of stop consonant production were made in study I. The computerized evaluation sheet in VISOR showed six columns, one for each vowel-consonant-vowel (VCV) syllable /i:pi:/, /i:bi:/, /i:ti:/, /i:di:/, /i:ki:/, /i:gi:/. Two different utterances of each syllable from each speaker were presented in random order and doubled, which gave a total of 96 voice samples (2 x 12 syllables x 4 speakers) from each listener. Five trained listeners (phoneticians and SLPs) made individual judgments of the VCV-syllables by placing the speech samples in the labeled columns, respectively.

Two of the listeners were also asked to make judgments about the speakers voice quality, using the parameters ‘hyperfunctional’, ‘hypofunction’, ‘breathiness’ and ‘roughness’. These judgments were made in a separate session as a test of using VISOR with visual analogue scales. Results from the judgments of voice quality were only reported as general comments of the voice quality in the speakers.



**Figure 3.** Example of the visual sort and rate (VISOR) method with vertically placed visual analogue scales.

Visual analogue scales in VISOR were used for *voice quality assessment* in study II. The parameters used were ‘hyperfunctional’, ‘breathy’, ‘rough’, and ‘gurgly’ (Figure 3). Operational definitions of the parameters were given orally and in writing to each listener before their assessment session. Two different voice samples were taken from the five TE-speakers and the four E-speakers. One sample consisted of two sentences from the text reading during the VRG-recording, and the second sample consisted of two sentences from the reading made in the sound-treated booth. Five trained listeners (SLPs), all with experience of laryngectomee speech in their clinical practice, judged the voice samples.

The perceptual speech and voice assessment in study IV was a 2-steps procedure. The first step was to develop a new protocol with VA-scales for speech and voice quality analysis of TE-speech. This was made in cooperation with the five SLPs who made the perceptual assessments in step 2. During session one, in which recordings of TE-speakers not included in the study were used, relevant parameters were determined. A preliminary protocol had been prepared beforehand. The parameters were discussed and defined in consensus during the session and a final protocol with a total of eleven parameters was produced.

In the second assessment session (with the same listeners) the perceptual data were collected. Ratings were made individually. The listeners were presented with randomly

ordered samples of the whole reading paragraph from all 35 subjects. Ten duplications (28%) were included for intra-rater analysis, i.e. all together 45 samples. The listeners were allowed to listen to the samples for as many times as needed. Information about each speaker's age and native language was given before presentation of each sample. Written operational definitions of the parameters were available during the listening session. The parameters 'general impression/degree of deviation', 'articulation', 'hyperfunctional', 'breathy', 'rough' and 'gurgly' were assessed on 100 mm VA-scales. The parameters 'phrase length', 'speaking rate', 'breathing pauses', 'intonation', and 'pitch' were assessed on 200 mm VA-scales with the mid-point marked 'normal', since ratings both below and above 'normal' could be expected. In the end of the protocol personal comments and/or additional parameters could be added. The protocol as well as the operational definitions can be seen in Appendix A and B in Study IV.

## 2.5 ACOUSTICAL ANALYSES

Acoustical analyses of speech and voice were made in study I, II, and IV. In each study, the acoustical measurements were made of the same speech samples as used for the perceptual assessments, with the exception of the recorded speech material during the VRG investigations in study II. The reason not to acoustically analyse the audio-recordings from the VRG was that noise from the VRG equipment affected the reliability of the fundamental frequency and intensity measurements. All acoustical measurements were made by use of the computer-based Soundswell signal workstation™ (Ternström 2000) solely, or in conjunction with other compatible programs or modules.

In study I, measurements of duration of the stop gap (closure duration) and voice onset time (VOT) in the syllables were made. The closure durations for the oral stop consonants were determined to begin after the last fundamental period of the preceding vowel and end at the start of the plosive burst. VOT was measured as the section following the closure, starting with the burst and ending right before the beginning of the first fundamental period of the second vowel. In addition, spectrograms of the syllables were made for analyses of voice bursts and aspiration.

Measurements of fundamental frequency (F0) were made in study II and IV with the use of the Soundswell analysis tool FoX. This program module offers a number of adjustments regarding both period-detecting algorithms and filtering of the signal. Since the vibratory pattern of the PE-segment in alaryngeal voices can be expected to be highly irregular, it is important to make relevant adjustments in filtering of the voice signal. Such adjustments can easily be checked in Soundswell by linking the analyzed output file in FoX with the input signal file. In study II, measurements of F0 were also made with the use of the Correlogram program. In this program, possible candidates for F0 are displayed in a three-dimension graph, and this method has proven to be helpful in analyses of F0 in voices with high degrees of irregular vibrations (Granqvist and Hammarberg 2003).

Voice intensity measurements are often given in SPL (dB), and speech samples are commonly sustained vowels or repeated syllables with equalized stress. The vowel

sample is chosen since this gives a 'steady' signal. Running speech is by definition a fluctuating signal that includes both voice and voiceless segments and varies in frequency and intensity due to the intonation pattern. Therefore, sound pressure level of running speech requires averaging over time. In the present investigation, study II and IV, voice intensity was calculated as the equalized mean of sound pressure level (Leq), i.e. the steady sound pressure level, which over a given period of time has the same total energy as the actual (fluctuating) sound that is being measured. In addition to the Soundswell Signal Workstation™, the program Phog™ (Saven Hitech AB) and a custom made measurement tool (Granqvist 2005) was used for measurements of Leq.

The temporal measurements in study IV were calculated with the speech signal visually displayed in the Soundswell program as an analysis screen. The signal was processed visually and acoustically simultaneously, with zooming of relevant parts of the signal. This procedure facilitated good precision in the measurement analyses. Measurements were made of a) total reading time of the reading paragraph (seconds), b) speaking rate (words per minute), c) articulation rate (syllables per minute), d) phrase length (syllables per breath), e) number of pauses, and f) percent pause time (proportion of total reading time/summarized pause time). Pauses were defined as periods of silence longer than 250 ms (Goldman Eisler 1968).

## 2.6 EVALUATION OF VOICE HANDICAP AND QUALITY OF LIFE

Self-evaluated voice handicap and health-related quality of life in laryngectomees were examined in study III. The self-evaluations were made with the use of the following questionnaires:

### Voice Handicap Index

Voice Handicap Index (VHI) is an instrument for self-assessment of voice problems developed by Jacobson et al (1997). The protocol consists of 30 statements on voice-related aspects in daily life. The patient is asked to indicate for each statement on a 5-point scale (0=never, 4=always) how it applies to his/her individual situation (see Appendix A). The statements can be grouped into three subscales, each with 10 items: a physical (VHI-P), a functional (VHI-F) and an emotional (VHI-E) scale. Each subscale score ranges from 0 to 40, thus making a total VHI score of 120. A total score between 0 and 30 is commonly interpreted to reflect a minimal/mild voice handicap, a score between 31 and 60 a moderate voice handicap, and scores from 61 to the maximal 120 a severe voice handicap (Voice Center, University of Pittsburgh).

VHI has been translated into several languages and is frequently used as a clinical tool. In study III, a translated and validated Swedish version (Ohlsson 2001) of the VHI was used for the participants' self-assessments of their voice handicap. A recent study involving eight European countries, among them Sweden, has shown that the translated and validated versions of the VHI in these countries were equivalent, i.e. comparisons of VHI-results from these countries can be made (Verdonck-de Leeuw et al 2008). VHI has been used in several research studies of various voice disorders (Rosen et al 2000; Holmberg et al 2007; Schindler et al 2008) and in previous studies regarding voice handicap in laryngectomees (Stewart et al 1998; Moerman et al 2004; Schuster et al 2004; Kazi et al 2007a).

## **EORTC QLQ-C30 and EORTC QLQ-H&N35**

As mentioned in the introduction, the European Organization for Research and Treatment of Cancer (EORTC) has developed cancer-specific questionnaires about health-related quality of life. The core questionnaire, EORTC QLQ-C30, was developed by Aaronson et al in 1993, and a further validation was made in a study by Kaasa et al (1995). A total of 30 questions comprise multi-item functional and symptom scales, a global quality of life scale, and single item questions. The five functional scales are: physical functioning, emotional functioning, role functioning, cognitive functioning, and social functioning. The three symptom scales are: fatigue, nausea/vomiting, and pain. The single item questions ask about dyspnea, insomnia, loss of appetite, diarrhea, constipation and financial difficulties. Two questions comprise the global quality of life-scale and ask about overall health status and quality of life. The patient is asked to answer questions about his/her health status during the past week.

EORTC QLQ-C30 captures the more general problems and treatment side-effects shared by many cancer patients, but it is too wide-ranging in terms of the specific problems due to tumor site and its specified treatment. Therefore, EORTC has also developed several tumor-specific quality of life questionnaires, which are mostly used in combination with the core questionnaire.

The specific questionnaire for head and neck cancer patients, EORTC QLQ-H&N-35, was developed by Bjordal et al (1999 and 2000). It consists of 35 questions, and similarly to the QLQ-C30, it uses a one-week frame for the answers. Several symptom scales are included, concerning problems with pain from the head and neck area, swallowing, senses (smell and taste), speech, social eating, social contact, and sexuality. The six single item questions are about problems with teeth, opening mouth, dry mouth, sticky saliva, coughing, and feeling of illness. In addition there are five yes/no-questions about use of pain-killers, nutritional supplements, feeding tube, and experience of weight loss or weight gain during the past week.

Scores from all questions in the EORTC QLQ-C30 and EORTC QLQ-H&N35 are transformed to a '0-100' score according to the EORTC QLQ scoring manual (Fayers et al 2001). The score of all scales and items in the two EORTC-questionnaires range from 0 to 100. High scores on the functional scales and the global quality of life-scale indicate a good function. High scores on the symptom scales and symptom items indicate a high level of severity, i.e. a bad status.

Swedish translations of the two EORTC-questionnaires, provided by the EORTC, were used in study III. For further information about these questionnaires, see [www.groups.eortc.be/qol](http://www.groups.eortc.be/qol)

## **2.7 STATISTICAL ANALYSES**

Statistical analysis included calculations of means and standard deviations for descriptive purposes.

In study I, intra- and inter-listener agreements in the perceptual categorical assessment were calculated as percent correct answers.

In study II Cronbach's alpha was used to calculate inter-rater reliability. In study IV inter-rater reliability was calculated using Kendall coefficient of concordance. Intra-rater reliability was calculated by means of Pearson's correlation coefficient, and Spearman's correlation coefficient was used for pairwise correlations between the

physiological, the perceptual and the acoustical analyses data in study II. In study IV, Spearman's correlation coefficient was chosen for calculations of intra-rater reliability and pairwise correlations between the perceptual and acoustical analyses data. Pearson's correlation coefficients were used for pairwise correlations between the self-reported voice handicap data and the perceptual and acoustical analyses data. In study IV, intra- and inter-rater reliability were also calculated for using intra-class correlation (ICC), to test the homogeneity within and between the listeners.

In study III, the analysis of VHI-scores was made as recommended by Jacobson et al (1997), and the analysis of the EORTC-questionnaires was made according to the EORTC QLQ scoring manual (Fayers et al 2001). Fisher's non-parametric permutation test was used for comparisons between two groups. For comparisons between several subgroups, the Kruskal-Wallis test was performed. Pitman's nonparametric test was used for correlation analysis of VHI- and EORTC-scores.

## **2.8 ETHICAL CONSIDERATIONS**

Informed consent was obtained from all participants in the studies. The studies were approved by ethical committees:

Study I: the Regional Ethical Committee at Karolinska Institutet, Dnr 95:11;

Study II: the Ethical Committee at Huddinge hospital, Dnr 175/92;

Study III and IV: the Northern Research Committee at Karolinska Institutet and Karolinska hospital, Dnr 03-465.



## 3 RESULTS

### 3.1 STUDY I

The aim of this study was to investigate the physiologic correlates of successfully produced voiced-voiceless stop consonants in four laryngectomee speakers (one E-speaker and 3 TE-speakers). Of particular interest was the determination of whether an opening gesture in the PE-segment could be made during production of voiceless stops, indicating volitional muscular activity in the alaryngeal voice source.

Intra-rater agreement in the perceptual assessment of the syllables was 94 to 98 %, and inter-rater agreement was 80 to 96 % for the five listeners. The misperceptions were mostly due to confusions within the same articulation place, i.e. between voiced and voiceless cognates. For one of the speakers, misperceptions were also due to confusions between articulation places.

The evaluation of the speakers' PE-segments revealed differences in shape with examples of circular shape in the E-speaker, and split side-to-side and triangular shape in the three TE-speakers. During phonation, location of vibrations was predominantly in the posterior wall for three of the speakers while the fourth speaker, with the triangular shaped PE-segment, had vibratory activity in the posterior, anterior and lateral pharyngeal walls.

*Speaker 1* mainly showed a regular pattern of both longer voice onset time (VOT) and longer oral closure duration phase for the voiceless stops compared to the voiced stops. He also signaled a difference between the stop consonants by using aspiration in voiceless stops. *Speaker 2* was misperceived in terms of confusions between the voiceless bilabial and dental consonants /p, t/ and their voiced cognates /b, d/. High-speed imaging analyses and spectrographic analyses of the syllables including /p/ and /t/ showed a period of continuing voice source vibration (voice bar) in the transition between the first vowel and the following consonant. *Speaker 3* made clear differences in VOT between the voiced and voiceless stop sounds. Spectrographic analyses of each syllable showed significant cues, such as aspiration in voiceless stops and very distinct voice bars in the voiced stops. For *speaker 4*, some voiced stops were perceived as their voiceless cognates. The spectrograms revealed weak voice bars in the voiced stop consonants, and a great deal of noise was seen between the formants in the following vowels, reflecting a breathy voice quality. By making the oral closure duration phases longer in the voiceless stops compared to the voiced stops the speaker tried to signal the difference between voiced and voiceless consonants, a strategy that proved to be successful at several occasions.

The results from the detailed analyses of high-speed imaging recordings in combination with simultaneous voice signal recordings showed that all four speakers were able to make differences between voiced and voiceless stop consonants by changing the muscular activity in the PE-segment. Although the speakers used a variety of phonatory and articulatory strategies, the vibrations in the PE-segment often stopped, and an opening gesture was seen during closure duration of a voiceless consonant. For voiced consonants, the vibrations in the PE-segment continued during the voiced consonants, although with decreased amplitude as compared to the previous and following vowels. Perceptual evaluation in comparison with acoustical analysis and high-speed imaging gave new insights about the speakers' different articulatory strategies.

### 3.2 STUDY II

This study aimed to relate the shape of the PE-segment from videoradiographical (VRG) measurements in E-speakers and TE-speakers with perceptual assessment of the speakers' voice quality and acoustic measurements of the voice function. It further aimed at investigating possible differences in appearance and placement of the voice source between E- and TE-speakers.

The measurements from the VRG of the PE-segments showed a variety of shapes and sizes. The metrical measurements for each speaker are presented in Table 4. As can be seen, the data show large inter-individual differences.

**Table 4.** Measurements of the PE-segment, during phonation (PHON) and at rest (REST): Prominence (PROM) of the PE-segment in the posterior wall of the pharynx towards the anterior wall. Minimal distance (MIN) between the posterior and anterior wall of the esophagus at the level of the PE-segment. Maximal distance (MAX) between the anterior and posterior wall of the esophagus below the PE segment. Surface area (SUR) of the PE segment. PROM, MIN and MAX are shown in mm, and SUR is shown in mm<sup>2</sup>. Beneath the individual subject data, Mean (SD) for the TE speakers, the E speakers and the whole group are shown respectively.

	PROM PHON	PROM REST	MIN PHON	MIN REST	MAX PHON	MAX REST	SUR PHON	SUR REST
1/TE	12.2	2.5	0	3.5	10	5	106	13
2/TE	16.3	4	0	2.5	14.3	7	193	61
3/TE	6.2	9	0	0	6	5	58	43
4/TE	15.3	12	0	5.5	11.3	14.5	151	152
5/TE	3.3	0	0	1.5	3.5	0	16	0
6/E	14.3	0	0	3.5	15.8	5	103	21
7/E	6.2	4.5	0	0	7.3	3	22	18
8/E	16.5	6	0	0	19.2	4.5	158	26
9/E	18.5	9	0	0	18.3	10	119	131
<b>Mean (SD)</b>	10.7	5.5		2.6	9	6.3	105	54
<b>TE-speakers</b>	(5.7)	(4.9)	0	(2.1)	(4.3)	(5.3)	(71)	(60)
<b>Mean (SD)</b>	13.9	4.9		0.9	15.2	5.6	100	49
<b>E-speakers</b>	(5.4)	(3.8)	0	(1.8)	(5.4)	(3.0)	(57)	(55)
<b>Mean (SD)</b>	12.1	5.2		1.8	11.7	6	103	52
<b>all speakers</b>	(5.5)	(4.2)	0	(2.9)	(5.5)	(4.2)	(61)	(54)

In two of the TE-speakers, two separate bulges in the posterior pharyngeal wall (PE area) were seen. In both these speakers, only one of the two bulges met with the anterior wall of the pharynx during phonation. This bulge was therefore considered to be the main place of phonation, i.e. the PE-segment.

For all but two E-speakers, the PE-segment was raised equivalent 0.5-1.5 vertebrae from resting position to the active position during phonation. Resting position of the segment varied from C4/5 to C6/7 in the whole group. During phonation the placement of the segment varied from C4/5 to C5/6.

The acoustical analysis showed that four of the male speakers and the two female speakers used a mean F0 in the range of normative data for male laryngeal speakers

(Pegoraro Krook 1988). Mean F0 (SD) for the TE-speakers was 111 Hz (23) and 108 Hz (22) for the E-speakers. Mean F0 (SD) for all nine speakers was 110 Hz (28). Voice intensity measurements (Leq dB) showed a close-to normal voice intensity, 67 dB (Corthals 2004), for the TE-speakers, while most of the E-speakers used a lower than normal voice intensity with a mean of 60 dB. Mean Leq for all speakers was 64 dB.

Perceptual assessments of the parameters 'hyperfunctional', 'breathy', 'rough' and 'gurgly' were made of two text samples ('text 1' and 'text 2'). The samples were duplicated to make possible calculation of intra-rater reliability. The intra-rater reliability tests showed statistically significant agreement for the parameters 'hyperfunctional' and 'breathy', but not for the parameters 'rough' and 'gurgly'. The inter-rater reliability for 'hyperfunctional' and 'breathy' was high, but the reliability coefficients for 'rough' and 'gurgly' were low. Due to the low intra- and inter-rater reliability for 'rough' and 'gurgly', these two parameters were not used in further analyses.

Mean value data of the listeners' judgment of each speakers showed a larger variation within the speaker group regarding the parameters 'hyperfunctional' and 'breathy' as compared to the other two parameters 'rough' and 'gurgly'. For a majority of the speakers (7 of 9) voice was judged to be relatively hyperfunctional with values above 450/1000, i.e. the listeners had mainly used the upper part of the scale in VISOR.

The measurement values for the nine speakers' individual PE-segment varied in terms of appearance and placement during both phonation and silence, but all speakers had a good closure (MIN-value = 0) at the PE-segment level during phonation (see Table 4). Since the number of subjects in this study was relatively small, and the variation within each speaker group large, no statistical calculations were made for comparisons between the two speaker groups. A strong significant correlation was found between prominence (PROM) of the PE-segment and the maximum (MAX) width beneath the PE-segment during phonation. Significant correlations were also found between PROM and surface area (SUR).

No relationships between the videoradiographical assessment, the acoustical analyses and the perceptual judgments were found. The only significant correlations were found between mean F0 and the two perceptual parameters 'hyperfunctional' and 'breathy'.

The conclusion of this study was that despite the individual differences regarding the PE-segment, a functional voice after laryngectomy is possible as long as there is a good closure at the PE-segment level during phonation.

### 3.3 STUDY III

The purpose of study III was to investigate the perceived voice handicap and health-related quality of life in a group of 43 laryngectomees. Furthermore, the investigation aimed to explore the relationships between degree of voice handicap and other health-related disabilities after cancer treatment and laryngectomy.

Comparisons between VHI-scores and quality of life-score for TE-speakers (n=38) and the EL-speakers (n=5) showed no significant differences between the speaker groups. Regarding gender, questionnaire results for the three women did not differ from the results for the men (n=40). Thus, the total results are shown for the whole group, regardless of speaking mode or gender. Results from the VHI-questionnaire are also

given for subgroups as regards age (<60, 60-69, ≥70 years) and length of postoperative period (<1, 1-5, ≥5 years).

Mean total VHI-score for the laryngectomees in this study was 48.0 (SD 21.2), range 12-99. The VHI severity degree showed that twenty-four participants (56 %) perceived their voice handicap as moderate (score 31-60). Twelve participants (28%) rated their handicap a severe voice handicap (score >61), and seven participants (16 %) rated their voice handicap as minimal/mild (score < 30). Results for the three subscales (physical, functional, and emotional) showed that the mean scores for the physical (18.6, SD 7.5) and functional (17.3, SD 7.4) scales were somewhat higher compared to means for the emotional (12.1, SD 8.9) scale, although the differences between the subscales were not statistically significant.

Participants younger than 60 years at the time of the investigation, received about ten points higher mean total VHI-scores (VHI 57.9, n=9) as compared to total values for the groups of the age of 60 to 69 years (VHI 48.8, n=16) and 70 years and older (total VHI 42.4, n=18). Length of the postoperative period also seemed to affect the VHI-scores. Mean VHI-score for the patients (n=9), who had lived as laryngectomees for less than a year, was 60.9. Mean VHI-score for patients who had lived as laryngectomees for 1-5 years was 47.8 (n=17), and mean scores for the patients who had lived as laryngectomees for more than five years was 41.6 (n=17). However, these differences were not statistically significant. The two statements receiving the highest VHI-score of all in the whole patient group reflected difficulties in making oneself heard and understood in a noisy room and difficulties to call out loudly.

The results from the EORTC-questionnaires are given as mean values between 0 and 100. A high value on a functional scale reflects a good function. A high value on a symptom scale/item reflects a high level of problems. The functional scales (physical, emotional, role, cognitive and social functioning) in the EORTC QLQ-C30 showed mean values between 74.8 and 82.6. Compared to these scales, the global quality of life scale (Global QOL) scored lower, with a mean of 66.8. The symptom scales and items in the EORTC QLQ-C30 received relatively low scores, i.e. the subjects did not have large problems in these areas. Dyspnea (36.4), fatigue (28.1), insomnia (23.3) and financial difficulties (20.9) were the only items resulting in scores higher than 20. The financial difficulties were mainly reported by the younger participants.

In the EORTC QLQ-H&N35 (with symptom scales/items only) the sense scale received the highest mean score, 65.1/100. This scale summarizes problems with both smell and taste. Several scales and items regarding speech, mouth and airway problems received mean scores between 30 and 40: speech problems (30.7), problems with teeth (37.3), sticky saliva (37.3), dry mouth (33.3), and coughing (31.0). The questions about sexuality received a mean score of 38.1. The mean score for swallowing problems was 24.4. This scale is a summary of three questions about difficulties with liquids, pureed and solid food. Sixteen patients (37%) reported difficulties with solid food. Nine of these 16 patients also reported difficulties eating together with others and enjoying their meals. The five single-item questions in the EORTC QLQ-H&N35 about use of analgesics, nutritional supplements, feeding tube, and experience of weight loss or weight gain were answered with 'no' by most patients and were excluded for further analysis.

Correlations between the Global QOL-scale and the other scales/items of the EORTC-questionnaires revealed significant relationship between Global QOL and all other functional scales. Significant correlations were also found between Global QOL and fatigue, appetite loss, insomnia, and pain. Several scales and items of the H&N35-questionnaire also correlated significantly with Global QOL, i.e. swallowing, sense problems, social eating, social contact, sexuality, dry mouth, sticky saliva, and feeling of illness. However, the speech scale and many of the aspects which may affect speech and respiration, i.e. teeth, mouth opening/trismus, dyspnea, and coughing, did not correlate significantly with Global QOL.

Correlation analysis between voice handicap and health-related quality of life revealed significant correlations between mean total VHI-score and all functional scales in the EORTC QLQ-C30. A statistically significant correlation between mean total VHI-score and the Global QOL-scale was also found. Regarding the symptom scales and items in the EORTC QLQ-C30, significant correlations were found between mean total VHI-score and nausea/vomiting, pain, dyspnea, and financial difficulties. Mean total VHI-score was also significantly correlated with several of the head and neck symptoms: pain, smell and taste problems, speech problems, social eating, social contact, and sexuality. No significant correlations were found between total VHI and the questions on teeth, dry mouth and sticky saliva.

In summary, the results from the EORTC QLQ-C30 showed mean scores of the functional scales in agreement with normative data, but the Global QOL-scale showed considerably lower scores compared to normative data. The H&N-questionnaire revealed high degree of problems with smell and taste, speech, coughing, and xerostomia. Degree of voice handicap was significantly correlated to the participants' scoring of Global QOL and on the functional scales, and with problems regarding breathing and speech, social contact, and meal situations. These relationships confirm that the perceived degree of voice handicap affects the individual's participation in social activities.

The results of the study also showed that the separate questionnaires do not capture all of the disabilities and symptoms after a laryngectomy, but that a combination of the EORTC-questionnaires and the VHI-questionnaire broadens the knowledge about the problems of a laryngectomee.

### 3.4 STUDY IV

The aim of the fourth study was to analyze trained listeners' ratings of TE-speakers with the use of a new protocol including both speech and voice quality parameters, and to analyze the TE-speakers' fundamental frequency, voice intensity and temporal speech aspects. It further aimed to examine pair-wise relationships between the perceptual ratings, acoustical measurements and self-reported voice handicap from the TE-speakers.

In the perceptual analyses, speech parameters with intra-rater reliability below 0.40 were excluded, which led to exclusion of one parameter: 'breathing pauses'. Mean intra-rater reliability for the ten remaining parameters was 0.62 (range 0.44-0.85). Mean inter-rater reliability was 0.59 (range 0.44-0.75).

The perceptual assessments of 'general impression/degree of deviance' resulted in a mean value of 69.9 mm (SD 14.2) on the 100 mm VAS, and no rating was below 40 mm. The specific voice quality parameters were rated as follows: 'rough' with the

highest rating (mean 54.9 mm, SD 17.1), followed by ‘gurgly’ (mean 44.0 mm, SD 25.7), ‘hyperfunctional’ (mean 42.3 mm, SD 17.1), and ‘breathy’ (mean 36.8 mm, SD 18.5). ‘Articulation’, also rated on 100 mm VAS, yielded a mean of 26.7 mm (SD 16.2).

‘Speaking rate’, ‘phrase length’, ‘intonation’ and ‘pitch’, assessed with 200 mm VA-scales, with 100 mm representing ‘normal’ were rated as follows: ‘Speaking rate’ yielded a mean rating of 88.9 mm (SD 12.4), and ‘phrase length’ a mean of 90.2 mm (SD 21.1). Twenty-seven of the 35 speakers (77 %) were judged to have a monotonous intonation. Mean rating for all speakers for ‘intonation’ was 71.4 mm (SD 15.2). ‘Pitch’ yielded a mean of 68.3 mm and demonstrated the highest variation among the raters (SD 33.6).

Results for the acoustical measurements showed a mean fundamental frequency (F0) for the whole speaker group of 109 Hz (SD 27.5 Hz). Mode F0 was lower, 96 Hz (SD 41.2 Hz). For fifteen speakers mean F0 was below 100 Hz and for 23 speakers, mode F0 was below 100 Hz. Apart from lower than mean values, Mode F0-range was wider, 48-273 Hz, compared to range for mean F0.

Mean voice intensity, expressed as Leq, was 69 dB (SD 4.5 dB). Forty-eight percent of the speaker group used intensity levels of 70-81 dB, while only five speakers used intensity levels below 65 dB.

Mean speaking rate for the group was 131 (SD 28) words per minute (wpm). Eight speakers used a speaking rate of less than 100 wpm. Four of those speakers were non-native Swedish speakers, and two suffered from affected mobility of the tongue base. Their low speaking rate was mainly caused by a high percent pause time. Articulation rate varied largely within the speaker group, with a range of 117 to 343 spm. Mean articulation rate was 264 spm (SD 51) for the whole group. Mean for number of pauses was 13 pauses for the whole passage (range 7-32). The majority of the group (77 %) made less than 15 pauses during reading of the paragraph, while four speakers made more than 20 pauses. Mean percent pause time was 26 (SD 6.9). Mean phrase length was 13 spb (SD 4.5), with a range of 4 to 27 spb.

The self-reported voice handicap by the 35 TE-speakers showed a mean total VHI-score of 46.9 (SD 22), ranging from 12 to 99 (of the possible maximum total score of 120). Mean scores (SD) for the three subscales were 16.9 (7.8) for VHI-P, 18.4 (7.5) for VHI-F, and 11.7 (9.2) for VHI-E (of the possible maximum of 40 respectively).

The perceptual assessments of intonation, hyperfunction, and breathiness were significantly correlated with high F0, whereas assessments of rough, gurgly and pitch were significantly correlated with low F0. Significant positive correlations were found between perceptually assessed pitch and measured F0, between assessed speaking rate and measured number of words per minute, and between assessed phrase length and measured number of syllables per breath. Mean score for the speakers’ total VHI and for the VHI-F were significantly and positively correlated to measured voice intensity and percent pause time. Significant positive correlations were found between the VHI-P score and total reading time and percent pause time. A significant negative correlation was found between the VHI-P score and phrase length. No significant correlations between the perceptual assessments and VHI were found.

## 4 GENERAL DISCUSSION

### 4.1 ANALYSES OF THE PE-SEGMENT

The high-speed imaging recordings in study I provided both general and detailed information about the shape and vibration pattern of the speakers' PE-segments seen from above. The high amount of pictures per second was a prerequisite for analysis of the ability to make opening gestures in the PE-segment during voiceless stop consonants. Possible adjustments regarding the contrast and the brightness of the images within the analysis equipment, the High-Speed Tool Box (Larsson et al 2000) were also a good help for accurate analyses. The nasofiberscope had an extra channel for suction, if needed. Although suction of mucus in the lower part of the pharynx might alternate the "real" voice, we decided to use this fiberscope based on experiences from previous trials with high-speed recordings in laryngectomees (Lundström and Hammarberg 1999). Mucus is often present at the entrance of the esophagus in a laryngectomee, and this gives the perceptual impression of a "gurgly" voice. However, in study I the main purpose was to investigate the volitional muscular control of the segment during production of voiceless and voice stop consonants, and not to make judgments about the voice quality.

The overall evaluation of the characteristics of the PE-segment showed that location of vibration and shape of the PE-segment were connected. The speakers who had the vibratory location predominantly in the posterior pharyngeal wall had a split side-to-side shape of their segments while the speaker with a triangular shaped segment had vibrations in the posterior, anterior and lateral walls.

Although individual differences were seen in the speakers' phonation and articulation of the syllables, the detailed analyses of the high-speed images showed that all four speakers were able to change the muscular activity in the PE-segment but that the intention to make differences between voiced and voiceless stop not always lead to a successful production of the speech sound. Hirose (1996), investigated eight E-speakers' ability to make transient openings in their PE-segments during production of voiceless sounds. Results showed that four of the speakers were able to make opening gestures, although there was a considerable intra-speaker variation, even for the same utterance.

As opposed to the muscular control of the posterior cricoarytenoid muscle in laryngeal production of voiceless sounds there is no specific abductor muscle in the PE-segment. The opening of the segment is probably due to a relaxation of musculature in the PE-area. During phonation the musculature in the PE-segment acts in combination with aerodynamic forces. To be able to make an opening gesture in the PE-segment during a voiceless sound the laryngectomee must make quick changes in muscle tonicity and also changes in air pressure beneath the PE-segment. Although the adjustments are not as consistent as in laryngeal voice production, alaryngeal voice production might be seen as an aerodynamic-myoelastic event (Moon and Weinberg 1987).

The results of the analyses of the speakers' PE-segment made in study I and II show that the placement, shape and size of the segment as well as the vibratory pattern differ from one laryngectomee to another. These results are in agreement with previous studies of both E- and TE-speakers (Diederich and Youngstrom 1966; Damsté and Lerman 1969; Omori et al 1994; Van As et al 1999 and 2001).

Although the VRG-measurements of the PE-segment used in study II cannot reflect the total dynamic pattern in the voice source, they still provide valuable information about characteristics of the PE-segment. Since the speakers were documented both during phonation and silence, information about changes in the PE-segment from rest position to voice production was gained from the measurements. Most values differed among the nine speakers but the minimal distance (MIN) between the PE-segment and the anterior wall during phonation was zero for all speakers (see Table 4). A zero-value for MIN means that closure is complete at this measure point. However, this value does not reflect the extent of the tissue contact area, i.e. whether the contact is between a long or a short portion of the posterior and anterior pharyngo-esophageal walls. Neither does it tell anything about the duration of the closure or the tenseness in the musculature. Furthermore, the VRG-measures were made only from a lateral view. The total closure pattern including the sidewalls of the pharynx is not known, which means that air leakage during phonation might still be possible. Two of the TE-speakers (no 3 and 5, see Table 4) were judged to have a high degree of breathiness despite the zero-value for MIN. These speakers had small PE-segments and irregularities in the back pharyngeal wall. Such irregularities can affect the air passage, resulting in a turbulent sound perceived as breathiness. A relatively large PE-segment, as was found for six of the nine speakers, is likely to give a broader closure of the tissue, which would decrease leakage of air. Although the size of the surface area seemed to have some effect on voice intensity, neither Leq nor F0 correlated significantly with any of the VRG-measurements used in study II.

During phonation, the E-speakers widened their esophagus beneath the PE-segment (MAX) more compared to the TE-speakers. One explanation for these MAX differences between the two speaker groups is the different conditions for air supply in E- and TE-speech. An E-speaker uses the space just beneath the PE-segment as an air reservoir, but a TE-speaker does not have to do that since he uses the air from his lungs. There were also individual differences in the MAX measurement among the speakers, possibly due to differences in elasticity of the tissue. A relatively elastic tissue should allow a larger widening, as compared to a more stiff tissue. The change in MAX-value from rest to phonation can therefore indicate stiffness in the tissue. Van As et al (2001) found significant correlations between judgments of voice quality, measured MIN and the ability to change the area beneath the PE-segment from silence to phonation (MAX-value). The TE-speakers, judged to have a 'good' voice quality had a significantly better closure between the pharyngeal walls during phonation, and could also increase their MAX-value more, compared to speakers judged to have a 'reasonable' or a 'poor' voice quality.

An observation confirming that aerodynamic changes affect the voice source was the upward shift of the segment that was seen during phonation. All TE-speakers, who had continuing air supply during phonation, and two out of four E-speakers, raised their PE-segment  $\frac{1}{2}$  –  $1 \frac{1}{2}$  vertebra from rest position to phonation. This finding corroborates data in earlier studies (Van As et al 2001; Op de Coul et al 2003), where an upward shift of the PE-segment was seen in several of the TE-speakers.

Fiberoptic examinations and VRG-investigations are both useful for observations of the PE-segment and for documenting reasons for a malfunctioning voice. If detailed analysis of the vibratory pattern is needed, nasofiberendoscopy in conjunction with high-speed imaging is the best choice. This is mostly done for research purposes since a



high-speed camera is seldom available in a clinical setting. Many laryngectomees tolerate the nasofiberoendoscopy quite well but for some, such an investigation might be difficult and also painful. This is possibly due to the deterioration in the nasal mucosa that often occurs as a consequence of the changed breathing pattern.

When there is a need to examine the PE-segment and the anatomical structures above and below the segment, VRG is the preferred technique. The measurements (Van As et al 2001) are useful since they direct us to look at specific parts of the PE-area. The increased use of computers in clinical settings, and the possibility to digitally store videoradiographical images including calibration, should simplify analyses and measurements of the PE-segment. Analyses of the PE-segment should also include descriptions of the dynamic changes within and around the segment. A VRG-investigation of the PE-segment can preferably include investigation of the swallowing function as well, since comparisons of the segment's function in phonation and swallowing may give important information about the muscle function and elasticity of the tissues.

## 4.2 PERCEPTUAL AND ACOUSTICAL ANALYSES

### *Study I*

The results of the categorical judgments of VCV-syllables showed high agreement within and between the listeners. Misperceptions were made, but these misperceptions were often made by all listeners and are thus likely to reflect something in the speaker's production of the speech sound. The acoustical signal and the detailed analysis of the high-speed images contributed to possible explanations of the misperceptions.

Expected acoustic characteristics of stop consonants were longer oral closure duration, longer VOT and aspiration for voiceless consonants as compared to their voiced cognates (Lisker and Abramson 1964; Fant 1973; Kent and Read 1992). Saito et al (2000) studied intervocalic voiced stop consonant /b/ and its cognate /p/ in 40 TE-speakers and found that speakers regarded as highly intelligible had both longer VOT and longer closure duration in voiceless stop consonants than in voiced consonants. Their spectrogram analyses also showed that speakers perceived as highly intelligible showed ceased vibrations during a voiceless stop and continuing vibration during a voiced cognate.

Since the voice of a laryngectomee is often characterized by aperiodic vibrations there were some difficulties in defining VOT. The voice signal of each syllable was continuously compared with spectrograms and this gave clues to where to set the boundaries for the oral closure phase and the VOT, although sometimes there was little or no indication of a burst.

For the speakers, who were perceptually evaluated as making a clear distinction between voiced and voiceless stops, several indications of this distinction were seen in the spectrographic analyses. For example, for the voiceless stops aspiration phases were seen, and for the voice stops voice bars indicated continuing phonation. Phonation and aspiration are considered as complementary phenomena in stop production in the Swedish language (Fant 1973), which may explain why the listeners perceived the voiceless bilabial and dental consonants produced by one speaker (no 2) as their voiced cognates. In other words, the speaker had difficulties to cease vibration in the PE-segment in the transition between the first vowel and the voiceless bilabial and dental consonant, which was shown in the spectrograms as a continuing voice bar at the

beginning of the oral closure phase. This phonatory pattern reflects what is commonly labeled as phonation offset. In studies by Robbins et al (1986), Saito et al (2000) and Searl and Ousley (2004) it has been hypothesized that the phonation offset is a cue to whether a sound is perceived as voiceless or voiced. The high-speed images in the present study confirmed this kind of phonatory pattern, i.e. continuing vibrations in the PE-segment were seen in the beginning of these stop consonants. The shortened closure duration, due to the problems with phonation offset, led to a nonexistent aspiration after the plosive burst. In combination with short VOT-values in the second vowel the perceptual impression for the listeners was that this speaker produced a voiced and not a voiceless stop. Perceptual assessment and acoustical spectrographic analyses is a good help for the SLP for discovering such articulatory and phonatory patterns. In a speech therapy setting, this speaker would probably benefit from instructions to lengthen the closure duration and thus build up the intra oral pressure for the release of an aspirated voiceless plosive.

The TE-speakers were perceived to produce more voiced than voiceless stops, a result that is in agreement with Doyle et al (1988). They found that the E- and TE-speakers were similarly intelligible in their overall production of voiced and voiceless consonants, but that the TE-speakers were perceived to produce better voiced consonants than the E-speakers. Only one of the TE-speakers in our study, who had a very breathy voice, was misperceived regarding some of his voiced stops, and then especially the bilabial stops.

#### *Study II and IV*

Intra- and inter-rater reliability in study II was high for two out of four parameters, namely 'hyperfunctional' and 'breathy'. For the parameters 'rough' and 'gurgly' both intra- and inter-rater reliability were too low to allow for correlation analyses with the acoustical and physiological measurements. The listener group consisted of highly experienced SLPs who had worked with speech rehabilitation of laryngectomees for several years. Although 'gurgly' was a new parameter, the listeners were well acquainted with the "liquid voice quality" that often occur in laryngectomees' voices, and had no difficulty in understanding the definition of the parameter. Roughness is also a well-known characteristic of laryngectomee voice. What possible explanations could there be to the bad intra- and inter-rater agreement? The listeners had not met in a pre-session to discuss and agree upon the definitions and grading of the parameters. Furthermore, the extra long and vertically placed scales in VISOR could have affected intra-rater agreement since the listeners are more used to horizontal 10 cm long scales. The findings of low reliability for two out of four parameters suggest that acquaintance with the protocol and consensuses regarding the parameters are needed for a good agreement. Therefore, the listening procedures changed in the following study.

In study IV a new protocol using visual analogue scales (VAS) for assessment of TE-speech was developed and used. Beside assessments of specific speech and voice parameters, the protocol also included assessment of an overall impression parameter, i.e. the degree of deviancy from normal. The methodology for this perceptual assessment was, as mentioned in section 2.4, a 2-steps procedure. The first step was to determine parameters and their definitions and this was done in consensus with the listener group. Thereafter the final protocol was produced with a total of eleven parameters. The second step was the actual assessment session when the perceptual data were collected. Ratings were made individually by the same listeners that took part

in the consensus listening. Before start of the rating session, the parameter definitions were repeated and voice samples, not used in the actual study, were played and rated. This training procedure increased the intra- and inter-rater reliability, and only one parameter, 'breathing pauses' had to be excluded.

The listeners rated the TE-speakers' voice and speech as being clearly deviant from normal. Both voice quality aspects (low pitch, rough and gurgly) and speech aspects (deviant articulation, low speaking rate and monotonous intonation) influenced the listeners' perception of degree of deviancy in TE-speech.

High mean F0 was significantly related to perceived high degrees of hyperfunctional and breathy voice qualities in both study II and IV. This relationship is often found also in laryngeal voices, especially in hyperfunctional voice disorders. Low mean and mode F0 showed significant relationships with rough and gurgly voice (study IV). The listeners proved to have a good ability to judge pitch, as shown by significant positive relationships between assessed 'pitch' and measured mean F0 ( $r=0.74$ ,  $p<0.001$ ) and mode F0 ( $r=0.86$ ,  $p<0.001$ ). Judging from the higher correlation coefficient for mode F0, mode F0 seems to have influenced the listeners' perception to a higher degree than mean F0. Mode F0 for the speakers in study IV was 96 Hz, and two thirds of the speakers ( $n=23$ ) had a mode F0 between 48 Hz and 100 Hz. Based on these findings we conclude that the mode F0 rather than mean F0 reflected the speakers habitual pitch.

Despite the possibility of adjustment for filtering of the voice signal in Soundswell, F0 measurements were quite troublesome in some of the laryngectomized speakers. The aperiodicity, in combination with a low level of the fundamental (L0) in many of the voices made it difficult to track the F0. For a weak signal, as is often found after the filtering processes (high- and low pass filtering), the program may well interpret the second harmonic as being the fundamental. This leads to jumps and octave leaps in the analysis of the signal, although the sound of the voice does not contain voice breaks or octave leaps. However, since the Soundswell offers simultaneous visual displays of the acoustic signal and its extracted signals, the F0 measurements can be controlled and possible errors can be corrected. The Correlogram program used in study II confirmed the measurements made in Soundswell.

Because of the great variability in F0-extraction and the difficulties with some of the F0-analyses, perturbation and related measurements were not used in the present studies. The accuracy of measurements of F0 in aperiodic voices such as in a very rough laryngeal voice or an alaryngeal voice has been discussed in several studies (Titze 1995; Van As et al 1998; Ma and Yiu 2005). Titze (1995) defined voice signals in subtypes, with type I as periodic or nearly periodic, type II as signals with subharmonic frequencies that approach the fundamental, and type III as aperiodic signals. In our experience, most laryngectomee voices would be classified as type II or type III-signals. Dependent on what analysis tool is used, the first and maybe the second signal type can be analysed with regard to perturbation in the signal. Perturbation analyses of type III-signals would be unlikely to give reliable results since the F0-extraction from aperiodic signals is problematic and often inaccurate.

The instruction to the speakers in study II and IV was to use their habitual voice intensity while reading. In study II, the four E-speakers had a mean of 60 dB and the five TE-speakers had a mean of 67 dB. Mean voice intensity for the 35 TE-speakers in

study IV was 69 dB, although almost half of the speakers (48 %) used voice intensity between 70 and 81 dB during reading.

In study IV, mean Leq dB was significantly related to mode F0 and to percent pause time. Thus, the TE-speakers who used relatively high voice intensity also used a high fundamental frequency. These speakers also needed longer pauses between the phrases, possibly to maintain the intensity level.

Temporal speech aspects were measured in study IV. Not surprisingly, a low speaking rate and short phrase length were related to a high percent pause time for the speakers. Individual data revealed that speakers who used many pauses (>20) also displayed short phrase lengths (4-8 spb), probably due to problems with the coordination of breathing and phonation. Although a TE-speaker uses pulmonary air for phonation it is obvious that breathing through a tracheostoma affects the speech breathing pattern. The speakers all used manual occlusion of their tracheostoma while speaking and uncovering it for air intake. This speaking manner probably increased the pause time and decreased the speaking rate. A few of the speakers also had air leakage around their tracheostoma during speech, mainly due to a less well-fitted stoma device. An air leak affects the breath support for speech, and the phrase length.

Recent studies focusing on the speech breathing kinematics in TE-speakers have shown that TE-speakers start phonation at higher lung volumes and terminate speech at lower vital capacity as compared to laryngeal speakers, although without being able to produce longer utterances (Bohnenkamp 2008). In addition to the common trouble-shooting regarding stoma devices, awareness of the breathing pattern and instructions in breathing techniques should be included in speech rehabilitation for TE-speakers.

Perceptual and acoustical analyses are important instruments for clinicians working with speech and voice disordered patients. Voice quality in laryngectomee speech is unlikely to be altered to any large extent by voice training because of the anatomical conditions in the PE-segment. However, speech and voice training aiming to increase the phrase length and decrease pause time might improve the ability to communicate

Post surgery recordings and acoustical analyses at certain time intervals, for example 1, 3 and 6 months after surgery, can give further insight about the development of laryngectomee voice and speech. In combination with pre surgery recording data, information regarding speaking habits such as speaking rate, pausing, articulation and dialect can be used for comparisons. This information should be of importance for the patient and can also give feed-back about the communicative skills still kept. Increased knowledge about the relationships between acoustical measurements and the self-perceived voice problems can assist the SLP in directing the speech and voice therapy, and focus on speech patterns that are possible to improve.

### **4.3 VOICE HANDICAP AND QUALITY OF LIFE**

From a clinical point of view, it is important to seek answers to what aspects of voice and speech that might contribute to the laryngectomee's own perspective of communication problems. A laryngectomee has often gone through a long and sometimes difficult period of treatment for cancer with the goal to preserve the larynx. When the larynx finally has to be removed, many patients are able to develop a new voice. This voice is however deviant in character and function. Some laryngectomees

say that “the surgery took away one voice problem and gave me another”. The degree of voice handicap and perceived quality of life depend on the laryngectomee’s communicative ability, how he/she learns to cope with the remaining functional disabilities and how these disabilities affect participation in social life (Eadie 2003).

In this investigation, voice handicap was investigated by use of the Voice Handicap Index (VHI). Since the participants in study IV had constituted the larger part of the participants in study III, results regarding VHI-scores did not show any major differences between these two studies. The results will therefore be discussed as a whole, except for the part where VHI is correlated with perceptual and acoustical analyses, analyses performed only for the 35 TE-speakers in study IV.

The majority of the patients perceived their voice handicap to be moderate. Previous studies of VHI in TE-speakers (Schuster et al 2004; Kazi et al 2007 a) also report a mean total VHI-score reflecting a moderate degree of handicap, although the scores were more equally distributed over the three severity degrees of the VHI in those studies.

Regarding the VHI subscales, scores were higher for the physical and functional subscales compared to the emotional subscale, although these differences were not significant. Many of the speakers experienced voice production as effortful, and the effort increased in noisy environments, in which the speakers had difficulties to make themselves heard. The inter-individual differences were larger for the emotional subscale than for the other subscales. Within the group in which the speakers assessed VHI as minimal or moderate, the scores for the emotional subscale were lower than in the group with high voice handicap ratings. In the latter group, the subscale scores were more equally distributed among the three scales, i.e. the speakers’ problems were more evenly distributed among the physical, functional and emotional areas.

According to a study by Van Gogh et al (2007), differences in VHI scores for group comparisons should be more than 15 points to have a statistical and clinical significance. The high mean VHI-score (60.9) in the group with recently laryngectomized patients suggest that the voice handicap is perceived as more severe by these patients than in the group who had a postoperative period of five years or longer (total VHI 41.6). No significant VHI differences were found between the subgroups in the present study despite the difference of more than 15 points between the above-mentioned patient groups. This is most probably due to the limited number of participants in the study. Age also seemed to be an important factor for the degree of voice handicap, with higher scores for the patients who were younger than 60 years compared to the patients older than 60 years. In the study by Kazi et al (2007 a), significant correlations were found between age and all three subscales of VHI, with higher scores in the younger age group.

Compared to normative Global QOL-scores (Michelson et al 2000), the laryngectomees’ Global QOL-score of 66.8 was 10 points lower than for a group of people, age 60 to 69 years, with physical problems such as heart disease (Global QOL 77.1). Global QOL-score from a group of healthy people in the same age group showed an even larger difference of nearly 20 points (Global QOL 85.2) compared to the laryngectomees’ score. Previous studies of Global QOL in laryngectomees have also reported scores above 80 (Nordgren et al 2003; Op de Coul 2005; Risberg-Berlin et al 2007). Thus, the laryngectomees in the present study rated their overall health and quality of life relatively low. Op de Coul et al (2005) mention that the score of 82 for

Global QOL of the TE-speakers in their study might be due to selection biases, since these patients were well rehabilitated as regards communication and highly motivated to participate in a clinical trial of a hands-free stoma device. The laryngectomees in the study by Risberg-Berlin et al (2007), scoring 83 to 85 on Global QOL, were a selected group of patients participating in a treatment program regarding olfaction.

Problems with eating affected the Global QOL level highly for the patients in the present investigation. Global QOL was significantly correlated to dry mouth, sticky saliva, swallowing problems, problems eating together with family and friends, and problems with smell and taste. The problem with scent perception, in combination with problems to swallow solid food is likely to be the reason to problems with enjoying a meal and eating together with others.

Problems with coughing and affected speech breathing due to the production of mucus from the lungs are frequent problems for many laryngectomees. However, the questions regarding breathing and coughing in the EORTC QLQ-H&N35 showed no relationship with the patients' rated Global QOL. It seems that the EORTC-questionnaires do not cover the specific problems for laryngectomees regarding mucus production, breathing and coughing. This finding was also acknowledged by Op de Coul et al (2005). Bronchial problems and production of mucus in conjunction with voice problems are not covered by the statements in VHI either.

The speech scale of EORTC QLQ-H&N35 consist of three question, one about hoarseness and the two others about troubles talking to other people and/or talking on the telephone. Sixty-five percent of the participants in the present study answered that they had not been hoarse during the past week and these ratings led to a low score of the speech scale as such. As a consequence, the speech scale did not show any relationship with the Global QOL-scale. However, Global QOL showed a significant relationship with the degree of voice handicap, and especially the degree of emotional voice handicap, VHI-E. Total VHI-scores were also highly significantly related to the emotional scale and social scale in the EORTC QLQ-C30, including questions about their feelings of depression and/or anxiety and how their medical treatment interferes with family life and social activities.

The correlations between total VHI and the scales and items of EORTC QLQ-H&N35 reflected the difficulties with voice function, and how the voice handicap affects social activities. A significant relation was found between VHI and the social contact scale, in which questions about interacting with family and friends, and with participation in public events are posed. A dysfunctional voice, which results in a high VHI, is likely to cause social difficulties and result in limited social contacts.

Previous studies of relationships between VHI scores and acoustic measures have focused mainly on voice quality aspects, as for example on measurements of voice F0, intensity and maximum phonation time (Hsiung et al 2002; Wheeler et al 2006; Woisard et al 2007). Hsiung et al (2002) and Wheeler et al (2006) conclude from their studies that the results of voice acoustical measurements cannot predict the degree of VHI scores in individuals with voice disorders.

In study IV, the aim was not to use the perceptual assessments or the acoustical measurements as predictors of the TE-speakers' degree of VHI, but we aimed at investigating relations between self-reported scores of VHI and perceptual and acoustical analyses. Significant relationships were found between the VHI physical subscale and long total reading time and high percent pause time. A significant relation

was also found between the physical subscale score and short phrase length. Mean score of the functional subscale and the total VHI-score showed significant relationship with high percent pause time. These relations point to that the speakers' perceived degree of voice handicap were affected by how much time they needed for reading the whole paragraph, how many syllables per breath they were able to produce, and how many pauses and/or how long pauses they needed to take. Speaking rate, phrase length and pausing are aspects of speech that should affect communication face to face or over the telephone. A relatively long pause might be misunderstood as signaling the end of the utterance, inviting the counterpart to start speaking. If and when this happens, the person who uses short phrases and long pauses often feels as if he is being interrupted while talking.

Mean score of the functional subscale as well as the total VHI-score also showed significant relationships with high voice intensity. In other words, a TE-speaker who uses a relatively loud voice also perceives a high functional voice handicap. It could be hypothesized that it would be the other way around. The specific statements of the functional subscale (see Appendix A, statements labeled 'F'), include problems with making oneself heard, having problems to speak in a noisy environment, and being asked to repeat oneself. It seems as if the speakers who use higher voice intensity try to make an effort without succeeding which might increase their feeling of being voice handicapped.

#### 4.4 SUMMARY AND CONCLUSIONS

Volitional control of the musculature in the PE-segment was seen in high-speed imaging recordings during production of voiceless and voiced stop consonants. The vibrations in the PE-segment often stopped, and an opening gesture was seen during closure duration of a voiceless consonant. In voiced consonants, the vibrations in the PE-segment continued, although with decreased amplitude compared to the surrounding vowels. The changes in the vibratory pattern as seen in the high-speed images, and the acoustical analyses of the correctly perceived as well as the misperceived stop consonants gave new insights, useful in a therapeutic intervention of the coordination of phonation and articulation.

Radiological analyses of changes in shape, size and placement of PE-segment showed a predominant location of the segment in the posterior wall of the pharynx. The physiological measurements showed inter-individual variations in terms of shape and size during both phonation and silence. All speakers were able to get a good closure between the PE-segment and the anterior wall of the pharynx during phonation. Placement of the segment in relation to the cervical column showed a variance from C4 to C7. During phonation the placement of the segment was higher than during rest (silence) for most speakers ( $\frac{1}{2}$  to  $1\frac{1}{2}$  vertebrae). No significant relationships between measurements of the PE-segment, perceptual analyses of voice quality and measurements of fundamental frequency and voice intensity were found.

Mean values for the acoustical measurements of fundamental frequency and voice intensity for TE-speakers were often found to be close to normative data, however with wide ranges that reveal large inter-individual differences within the speaker group.

Speaking rate in TE-speakers was slower compared to normative data. Many TE-speakers had short phrase lengths and a high number of pauses which affected the speaking rate and the total reading time of a paragraph. Breath control and stoma occlusion are probable causes to short phrase length and high percent pause time.

A protocol using VAS for perceptual ratings of TE-speech and voice proved to be a reliable tool for individual ratings by SLPs when assessments were made after a session including training and discussion of definitions of the perceptual parameters. Deviant voice quality but also deviant speech temporal aspects such as lower speaking rate and shorter phrase lengths influenced the listeners' assessments of overall degree of deviation.

Degree of voice handicap as indicated by VHI was rated as moderate by more than fifty percent of the laryngectomees. Almost a third of the speakers rated their voice handicap as severe. Results for the three subscales of VHI showed that the physical and functional scales were scored somewhat higher compared to the emotional scale. The highest VHI-scores were given for statements about difficulties in speaking with a loud voice and making oneself heard and understood in a noisy room.

The functional and physical subscales of VHI showed significant relationship with voice intensity, total reading time, phrase length and percent pause time. The emotional subscale of VHI showed no relation with acoustical measurements. Perceptual assessments of TE-speech and voice showed no relationship with the speakers' self-reported voice handicap.

The laryngectomees' ratings on the functional scales in the EORTC-questionnaire showed mean scores in agreement with normative data. However, the Global quality of life-scale (Global QOL) showed considerably lower scores as compared to normative data. The EORTC-questionnaire also revealed high degree of problems with smell and taste, speech, coughing, and xerostomia.

Degree of voice handicap showed significant relationship with the scoring of Global QOL and the functional scales of EORTC. Voice handicap was also significantly related to problems with breathing and speech, social contacts and meal situations, smell and taste, and pain from the head and neck area. These relationships confirm that the perceived degree of voice handicap affects the individual's participation in social activities.

A combination of the EORTC-questionnaires and the VHI-questionnaire is recommended. Investigation of the relations between degree of voice handicap and health-related quality of life broadens the knowledge about the laryngectomee's problems.



#### 4.5 CLINICAL IMPLICATIONS AND FUTURE PERSPECTIVES

Since the introduction of voice prostheses the rehabilitation of TE-speakers has mostly been focusing on the practical care of the prosthesis, the tracheostoma and stoma devices. Although these aspects are important, speech therapy is also needed. The results of the present investigation show that TE-speakers have a low speaking rate and high percent pause time. Self-reported voice handicap degree from the speakers showed relationship with total reading time and percent pause time. Treatment which emphasizes coordination of breathing and phonation and fluency might improve these patterns in rate and pausing.

In conjunction with judgment of speaking rate and deviant voice quality, deviant articulation proved to be important for the listeners' judgment of overall degree of deviancy in TE-speech. The results in study I show that a laryngectomee has a volitional control of the vibrations in the PE-segment to some extent, but also that some articulatory strategies were stressed in order to increase intelligibility of voice and voiceless speech sounds. As a conclusion from these results, the SLP can focus the speech rehabilitation on techniques that help the speaker sustain oral closure to achieve intra oral and pharyngeal pressure high enough for distinct production of voiceless consonants.

Laryngectomees treated with postoperative radiotherapy can get a swollen pharyngeal mucosa as a side-effect, which affects both the size and the vibratory pattern in the segment and may prohibit vibrations to start. Nasofiberoscopic investigations of the PE-segment can verify edema. However, a VRG is needed to be able to document the PE-segment as well as the surrounding anatomical structures. VRG is also needed if one wants to have information about the function of the voice prosthesis, i.e. if air from the lungs is allowed to enter the esophagus or not.

Although the VRG increases the patient's exposure of radiation, a study regarding possible development and change in the PE-segment during the first months of speech would contribute to new knowledge of interest for intervention strategies.

A randomized treatment study focusing on different aspects of speech (breathing, phonation, articulation) would give further knowledge about possible effects of different treatment strategies on communication skills and voice handicap.

A prospective study using VHI for patients before and after laryngectomy would give further insight in coping strategies and acceptance of the changes in voice function in relation to age and length of postoperative period. VHI is easy to distribute and the time to fill out the form is reasonable in relation to the information gained from the questionnaire. EORTC-questionnaires can also be used at certain occasions, preferably in conjunction with the recurrent controls at the ENT-clinic. A combination of VHI and EORTC over time can give further knowledge about the coping in life situation after laryngectomy. Results from the present investigation show the need to use additional questions regarding specific problems with tracheostomal breathing and mucus production, and coughing.

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# APPENDIX A

## Voice Handicap Index (VHI)

Date:

Name:

These are statements that many people have used to describe their voices and the effect of their voices on their lives. Circle the response that indicates how frequently you have the same experience.

**0=Never    1=Almost never    2=Sometimes    3=Almost always    4=Always**

F	1	My voice makes it difficult for people to hear me	0	1	2	3	4
P	2	I run out of air when I talk	0	1	2	3	4
F	3	People have difficulty understanding me in a noisy room	0	1	2	3	4
P	4	The sound of my voice varies throughout the day	0	1	2	3	4
F	5	My family has difficulty hearing me when I call them throughout the house	0	1	2	3	4
F	6	I use the phone less often than I would like to	0	1	2	3	4
E	7	I am tense when talking to others because of my voice	0	1	2	3	4
F	8	I tend to avoid groups of people because of my voice	0	1	2	3	4
E	9	People seem irritated with my voice	0	1	2	3	4
P	10	People ask: "What's wrong with your voice?"	0	1	2	3	4
F	11	I speak with friends, neighbours or relatives less often because of my voice	0	1	2	3	4
F	12	People ask me to repeat myself when speaking face-to-face	0	1	2	3	4
P	13	My voice sounds creaky and dry	0	1	2	3	4
P	14	I feel as though I have to strain to produce voice	0	1	2	3	4
E	15	I find other people don't understand my voice problem	0	1	2	3	4
F	16	My voice difficulties restrict personal and social life	0	1	2	3	4
P	17	The clarity of my voice is unpredictable	0	1	2	3	4
P	18	I try to change my voice to sound different	0	1	2	3	4
F	19	I feel left out of conversations because of my voice	0	1	2	3	4
P	20	I use a great deal of effort to speak	0	1	2	3	4
P	21	My voice is worse in the evening	0	1	2	3	4
F	22	My voice problem causes me to lose income	0	1	2	3	4
E	23	My voice problem upsets me	0	1	2	3	4
E	24	I am less outgoing because of my voice problem	0	1	2	3	4
E	25	My voice makes me feel handicapped	0	1	2	3	4
P	26	My voice "gives out" on me in the middle of speaking	0	1	2	3	4
E	27	I feel annoyed when people ask me to repeat	0	1	2	3	4
E	28	I feel embarrassed when people ask me to repeat	0	1	2	3	4
E	29	My voice makes me feel incompetent	0	1	2	3	4
E	30	I am ashamed of my voice problem	0	1	2	3	4

Jacobson B, Johnson A, Grywalski C, Silbergleit A, Jacobson G, Benninger M, Newman C (1997). The Voice Handicap Index (VHI): development and validation. *Am J Speech Lang Pathol.* 6:66-70.

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