



Tracheoesophageal speech: A dedicated objective acoustic assessment[☆]

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Abstract

After total laryngectomy, the placement of a tracheoesophageal (TE) prosthesis offers the possibility to recover a new voice. However, the quality of the resulting TE speech is known to be degraded. To assess a patient's voice, current approaches rely either on quality-of-life questionnaires or on a perceptual evaluation carried out by speech therapists. These two methods exhibit the disadvantage of being both subjective and time-consuming. In this paper, we propose a dedicated scale, called A4S, for the objective Automatic Acoustic Assessment of Alaryngeal Speech. For this purpose, we first identify the artefacts existing in TE speech. These are linked to the periodicity, regularity, high-frequency noise and gargling noise/creakiness of the signal, as well as to the speaking rate. Specific acoustic features are proposed for the characterization of each artefact. A statistical study shows that TE speakers have a significantly worse voice compared to the control group, except for the speaking rate. Based on these advances, the A4S scale is proposed. This scale is made of five normalized dimensions, related to the five identified artefacts. A given patient's phonation can then be represented by a pentagon in a radar chart, which allows a fast and intuitive visualization of the strengths and flaws of the voice. A4S can then be seen as a useful tool for speech therapists to design tailored exercises specific to the patient's voice. In addition, we show the applicability of A4S for the follow-up of patients, as well as to study the impact of the type of surgery (open neck, robot and flap reconstruction) used for total laryngectomy and of a pre-surgical radiotherapy on various aspects of the TE voice.

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1. Introduction

A total laryngectomy (TL) refers to the removal of the entire larynx and separation of the airway from the mouth, nose and esophagus. As a consequence, patients who underwent TL cannot produce speech sounds in a conventional manner because their vocal folds have been removed. The main goal of the post-surgery process therefore consists in regaining a new voice. Three main options are nowadays possible for voice restoration after TL: esophageal, electrolaryngeal

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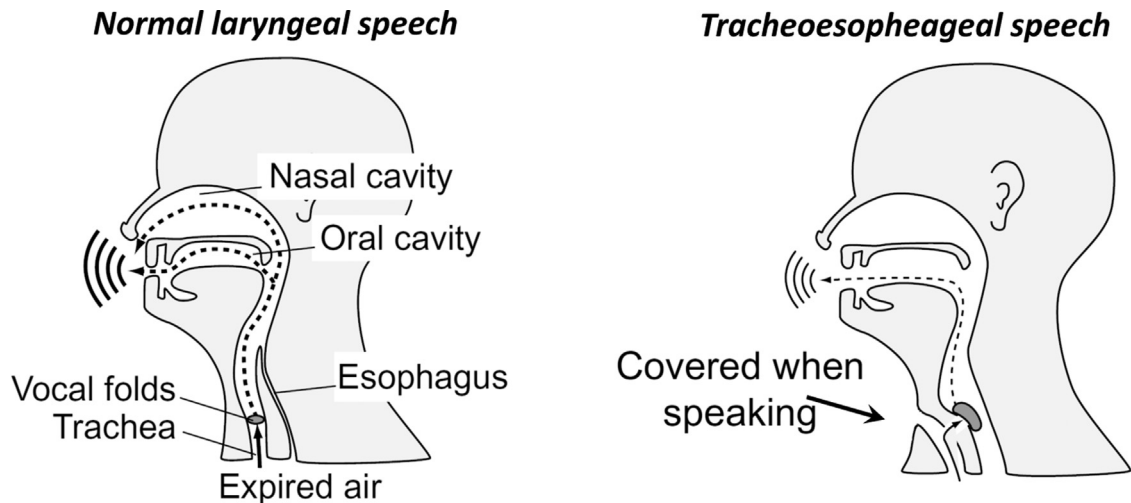


Fig. 1. Physiology of the vocal apparatus (adapted from Nakamura, 2010) for: *Left panel*: a normal subject with laryngeal speech; *Right panel*: a patient with a TE prosthesis. In this latter case, the tracheostoma must be covered (either with a finger or using a valve) when speaking.

and tracheoesophageal speech. In this manuscript, we focus on the analysis of tracheoesophageal (TE) speech as it has been shown in several studies (Baggs and Pine, 1983; Most et al., 2000; Robbins et al., 1984; Singer et al., 2012), to lead to superior voice rehabilitation capabilities compared to both esophageal and electrolaryngeal speech.

Since the esophagus and trachea are separated after TL, a hole called *tracheostoma* is created in the patient's neck to allow breathing. In TE speech, a surgical fistula (called *TE puncture*) is created in the wall separating the trachea and esophagus, allowing the placement of a phonatory prosthesis. The physiological differences before laryngectomy, and after the creation of the TE puncture are illustrated in Fig. 1. The TE phonatory prosthesis acts like a one-way valve: an airflow can pass from the trachea to the esophagus and further to the vocal tract cavities, allowing the production of speech; the passage from the esophagus to the trachea is however made impossible to avoid that food or drinks ingested by the patient penetrate in the trachea and go down to the lungs.

When producing TE speech, the airflow passing through the phonatory prosthesis generates, for some patients, the vibration of some residual organs called the *pharyngoesophageal (PE) segment*. When a control of this *neovibrator* (also sometimes referred to as *neoglottis*) is possible, patients are able to produce voiced sounds, but generally with a lower level of periodicity. As a consequence, albeit TE speech allows to recover a new means to communicate, it suffers most of the time from a clear diminution of naturalness and intelligibility (Most et al., 2000). In addition, the individuality/personality of the speaker is often lost (especially for female patients), mostly because of two main reasons: (i) the vibration of the neoglottis generally occurs at a (much) lower fundamental frequency compared to the normal laryngeal voice; (ii) the spectral shaping imposed by the vibration of the neoglottis can be radically different from that of the vocal folds. In Singer et al. (2012), these drawbacks were observed even in a more pronounced way for esophageal and electrolaryngeal speech.

Several works have targeted the evaluation of the way TE speech is perceived. Its acceptability and intelligibility have been compared in Most et al. (2000) to those of both laryngeal and esophageal speech. Although both aspects are degraded when compared to normal laryngeal speech, it turns out that TE speech is perceived to be more acceptable than good esophageal speech while they have a similar level of intelligibility. The study conducted in Singer et al. (2012) investigated the evolution of the intelligibility in alaryngeal speech during the first year following the TL surgery. Patients with a TE prosthesis were observed to have the best results. The authors also emphasized the improvement made by these patients within the first year, as well as the necessity to attend rehabilitation sessions during that period. Several works have targeted the evaluation of the way TE speech is perceived. Its acceptability and intelligibility have been compared in Most et al. (2000) to those of both laryngeal and esophageal speech. Although both aspects are degraded when compared to normal laryngeal speech, it turns out that TE speech is perceived to be more acceptable than good esophageal speech while they have a similar level of intelligibility. The study conducted in Singer et al. (2012) investigated the evolution of the intelligibility in alaryngeal speech during the first year following the TL surgery.

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