Analysis of failure of voice production by a sound-producing voice prosthesis

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Abstract

Objective: To analyse the cause of failing voice production by a sound-producing voice prosthesis (SPVP).

Methods: The functioning of a prototype SPVP is described in a female laryngectomee before and after its sound-producing mechanism was impeded by tracheal phlegm. This assessment included: perceptual voice evaluation of read-aloud prose by an expert listener; inspection of the malfunctioning SPVP; and aero-acoustical in vivo registrations using a computer-based data acquisition system.

Results: Sound-producing voice prosthesis speech is higher pitched, stronger, contains less aperiodic noise and requires a lower airflow rate than the patient’s regular tracheoesophageal (TE) shunt speech. Tracheal phlegm caused malfunction of the vibrating silicone lip of the SPVP by causing it to stick to its stainless steel container in an opened position, thereby reducing the SPVP to no more than a regular TE shunt valve from a functional point of view. Tracheal phonatory pressure and dynamic vocal intensity range were not affected by the functional status of the SPVP.

Conclusions: To exploit the advantages an SPVP could offer female laryngectomees with an atonic or severely hypotonic pharyngoesophageal segment, the sound-producing mechanism of the SPVP needs to be less vulnerable to tracheal phlegm.

Key words: Laryngectomy; Artificial Larynx; Voice Prosthesis; Alaryngeal Speech; Prosthesis Failure

Introduction

In order to improve voice quality and suitability for female laryngectomees and laryngectomees with a hypotonic pharyngoesophageal (PE) segment, a small pneumatic sound source, to be incorporated into a regular tracheoesophageal (TE) shunt valve, was conceived. The sound source consists of a bent silicone lip which performs self-sustaining oscillations driven by the expired pulmonary air that flow along the outward-striking lip through the TE shunt valve. The resulting frequency of oscillation and sound intensity can be modified by altering the airflow along the lip. To allow easy placement and removal of the sound source in our experimental setting, the bent silicone lip is fitted into a small stainless steel container (Figure 1) that can be partly inserted into a patient’s Groningen ultra-low resistance (ULR) shunt valve (Figure 2).

Preceding in vivo studies proved the feasibility of such voice production and provided us with directions for the development of an updated series of sound-producing voice prostheses (SPVPs). These were evaluated in vitro by aero-acoustic measurements and detailed high-speed photographic sequences to establish the most promising sound source configuration for clinical use. In a group of 20 laryngectomized patients, the selected prototype SPVP was successful in raising vocal pitch. However, only female laryngectomees with an atonic or severely hypotonic PE segment could benefit from a stronger voice with the current SPVP, generally in exchange for a reduction of intelligibility and communicative suitability.

A remarkable observation of the latter study was that, for 12 out of 20 patients (60 per cent), the test sequence had to be interrupted at least once because of tracheal phlegm impeding the vibrating silicone lip of the SPVP. Without this vibrating lip, the patients could still speak using their regular TE shunt voice. The tests could only be resumed after the SPVP had been removed from the patient, cleaned and reinserted. The current paper describes in detail several aspects of the functioning of a prototype SPVP before and after its sound-producing mechanism was impeded by tracheal phlegm.

Materials and methods

Patient

Our female patient was 80 years old at the time of this study. She underwent total laryngectomy with...
primary TE puncture and bilateral modified radical neck dissection 11 years before because of a recurrence after radiotherapy for a T2N1 supraglottic carcinoma. She did not have a primary pharyngeal myotomy or post-operative radiotherapy. Based on post-operative videofluoroscopic observations and voice characteristics, the patient’s PE segment tonicity was judged to be hypotonic. Spoken and written informed consent was obtained. The research protocol was approved by the medical ethics committee of the Vrije Universiteit Medical Centre, Amsterdam.

Procedure
The patient regularly used a Groningen ULR shunt valve and received a new one prior to the tests. Before being recorded with the new sound-producing module inserted into her TE shunt valve, the patient was encouraged to practice this new mechanism of alaryngeal voice for approximately half an hour. All the voice recordings and aerocoustical registrations described below were made twice in a sound-treated room, once with a functioning SPVP and once with a malfunctioning SPVP. During the first sequence of registrations, the patient experienced malfunction of the SPVP. With the malfunctioning SPVP in situ, a second sequence of registrations was made. After removing the sound source from the patient’s TE shunt valve and photographing, cleaning and reinserting it, the first sequence of registrations was completed with the SPVP functioning again.

Perceptual voice evaluation by a professional listener
Digital voice recordings were made using a microphone (MKE 212-3, Sennheiser, Germany) and a standard computer-based, 16 bit soundcard at 22 kHz. The patient was asked to read the first paragraphs of the Dutch prose passage ‘De Vijvervrouw’ in a normal conversational manner. A subset of the seven-point bipolar semantic scales, developed by Nieboer and later modified, was adapted for our purpose. This subset included the five scales ‘low pitch – high pitch’, ‘weak – powerful’, ‘tense – non-tense’, ‘gurgling – non-gurgling’ and ‘monotonous – melodious’. The digital recordings were presented in a random order to a voice-and-speech pathologist (IMV-dL) experienced with laryngectomized speakers in general but blinded to the status of the SPVP (i.e. functional or non-functional) in these recordings.
Acoustical and aerodynamic assessment

Registrations of sustained vowels were made with the experimental set-up shown in Figure 3. Tracheal phonatory pressure was measured by a pressure transducer (DT-2-14P-0-10L, Modus Instruments, Clinton MA, USA) connected to a tracheostoma adapter (BE-6040, Inhealth Technologies, Carpenteria CA, USA). A heated screen-pneumotach with integrated differential pressure transducer (MS-B and PT36, Erich Jaeger GmbH, Höchberg, Germany) was fitted onto a facemask (King Systems, Noblesville IN, USA) to determine phonatory airflow rate. A miniature electret condenser microphone with a hybrid integrated amplifier (9468, Microtronic, Amsterdam, Netherlands) was attached to the flowhead for voice recording. Sound pressure level at 30 cm from the flowhead on the facemask was registered by a digital sound survey meter (CEL-231, CEL Instruments, Hitchin, England). An 8-F catheter with three pressure transducers (UniTip 8366-00-9980-D, UniSensor AG, Attikon, Switzerland) was inserted through the nose until the distal sensor was located at the level of the oesophageal flange of the TE shunt valve. All sensor signals were pre-processed using National Instruments SCXI signal-conditioning hardware, sampled at 10 kHz by means of a computer-based, 16 bit, analogue-digital converter (PCI-MIO-16xle-10, National Instruments, Austin TX, USA), and digitally processed by a custom-built LabVIEW® software application. Recordings were made during several sustained phonations of the vowels /æ/, /ɪ/ and /u:/ at comfortable loudness and pitch. In addition, the patient was asked to sustain the vowel /æ/ as soft as possible and as loud as possible. In this way, the dynamic vocal intensity range was determined. Infratracheal pressure, oesophageal pressure, airflow rate and sound pressure level were read off-line from the raw data.

Results and analysis

After using the SPVP for approximately 45 minutes, the patient experienced clogging of the SPVP by tracheal phlegm. Forced exhalation through the SPVP cleared the prosthesis of phlegm, but the sound-producing mechanism no longer functioned after this incident. After removal of the sound source from the patient’s TE shunt valve and photographing, cleaning and reinserting it, the SPVP functioned properly again. Approximately 30 minutes later, the SPVP stopped functioning again, upon which it was removed and the test sessions ended. The
photographs of the malfunctioning SPVP are shown in Figure 4. The vibrating silicone lip was stuck to its stainless steel container in an opened position. Functionally, without the vibrating lip, the SPVP becomes no more than a regular TE shunt valve.

Perceptual voice evaluation by a professional listener

The recording of prose read aloud with a functioning SPVP was judged to be two scale values higher pitched than the recording of the malfunctioning SPVP. Moreover, the functioning SPVP was judged to be one scale value more powerful and one scale value less gurgling (Figure 5). Both SPVP speech and regular TE shunt speech when the SPVP malfunctioned were considered to be slightly monotonous.

Acoustical and aerodynamic assessment

Both the functioning SPVP and the malfunctioning SPVP enabled the patient to attain a maximal vocal intensity of 76[dB][A] at 30 cm from the flowhead on the facemask. The softest possible phonation of the vowel /æ/ fluctuated between 43 and 56[dB][A], irrespective of the functioning of the SPVP. Consequently, the dynamic vocal intensity range was 33[dB] for both conditions of the prosthesis.

Figure 6 shows registrations of sustained phonations of the vowel /æ/ at comfortable loudness and pitch. For all vowels, tracheal phonatory pressure was approximately 3.5[kPa], irrespective of the functioning of the SPVP. However, two apparent differences were observed when comparing registrations of the functioning SPVP (Figure 6a) to those recorded when the vibrating silicone lip was stuck to the stainless steel container in an opened position and only regular TE shunt voice remained (Figure 6b). First, the airflow rate was approximately tripled when the SPVP stopped functioning. Second, the pressure difference of 0.7–2.5[kPa] over the SPVP was eliminated when the SPVP stopped functioning; instead, an identical pressure difference was measured between the pharyngeal and the oesophageal pressure transducers of the catheter. This pressure difference forms the driving force for the self-sustaining oscillations of either the bent silicone lip in the functioning SPVP, or the patient’s PE segment when the SPVP is non-functioning.

Figure 7 shows sample spectrograms of two recordings of Dutch prose read aloud for perceptual voice evaluation. Figure 7(a) shows the recording of the functioning SPVP, with a tonal voice rich in higher harmonics, the fundamental frequency (f₀) ranging from 195 to 315 Hz. Figure 7(b) shows the malfunctioning SPVP; an aperiodic noise signal is seen, with occasionally recognizable low-frequency vibrations of the patient’s PE segment (f₀ < 100 Hz).

Discussion

In a similar, preceding study, the test sequence had to be interrupted at least once for 12 of the 20 patients (60 per cent) because of tracheal phlegm impeding the vibrating silicone lip of the SPVP. Tracheal phlegm problems are experienced by 91 per cent of all laryngectomees, and 85 per cent of all laryngectomees have to clean their stoma more than once a day. Prolonged extramural use of the SPVP would however require a permanent fixation or integration of the sound source into the TE shunt valve. Without the possibility of removal for cleaning, as in the present prototype, this suggests that a less vulnerable mechanism is required before a shunt valve can be permanently fitted within the sound source. The intention of the current pilot
trial was to allow a small number of female laryngectomees (who had successfully used the SPVP in one of our previous studies) to use the SPVP at home for as long as it was operative and to evaluate their voices weekly. The first patient, however, experienced malfunction before she could leave our out-patient department, as described above.

This study revealed that, as a result of tracheal phlegm, the vibrating silicone lip of the SPVP stuck to its stainless steel container in an opened position, as opposed to obstructing completely. Functionally, without the vibrating lip, the SPVP became no more than a regular TE shunt valve. This is consistent with our earlier observation\(^5\) that patients could still speak using their regular TE shunt voice when the SPVP malfunctioned. Therefore, the differences observed in the perceptual voice evaluation (Figure 5) reflected only the advantages a well functioning SPVP conferred on a female laryngectomme, as compared with her regular TE shunt voice. The sample spectrograms of readings of Dutch prose (Figure 7) illustrate these differences in an additional way; SPVP speech was higher pitched, stronger and contained less aperiodic noise than the regular TE shunt speech which remained when the SPVP malfunctioned.

Tracheal phonatory pressure and dynamic vocal intensity range proved not to be affected by the functional status of the SPVP. To enable regular TE shunt speech, the patient’s PE segment requires approximately the same pressure difference as does the bent silicone lip for SPVP speech. This pressure difference is the driving force for the self-sustaining oscillations of these structures. The airflow rate, however, is approximately tripled when the SPVP stops functioning and regular TE shunt speech remains (Figure 6). Consequently, the well functioning SPVP can be considered a more efficient voice source than the patient’s PE segment.

It has been assumed that biofilm formation on the oesophageal side of regular TE shunt valves is the main cause of leakage and increased airflow resistance, interfering with proper opening and closure of the one-way valve.\(^11,12\) However, biofilm formation takes weeks and therefore could not have been involved in the described SPVP malfunction, which occurred within an hour of placement. The importance of extracellular polymeric substances and connecting slime threads in maintaining the integrity of biofilms on voice prostheses has been shown.\(^13\) These might also function as glue to stick the vibrating silicone lip of the SPVP to its stainless steel container in an opened position. Mucolytics, antimycotics, probiotics and several surface modifications of the silicone rubber have been proposed to prevent biofilm formation.\(^14\) However, these methods seem unlikely to prevent the rapid malfunctioning of the sound-producing mechanism of the SPVP on the tracheal side of
the TE shunt valve. Better results might be obtained by altering the structural design of the SPVP to decrease its susceptibility to tracheal phlegm adhesion.

**Conclusion**

In agreement with our preceding studies, this paper demonstrates the advantages a well functioning SPVP can offer female laryngectomees with an
to exploit these advantages, however, the sound-producing mechanism of the SPVP needs to be less vulnerable to tracheal phlegm, which causes its vibrating silicone lip to stick to the stainless steel container in an opened position, thereby reducing its function to that of a regular TE shunt valve.
Female laryngectomees often have severe problems accepting their low-pitched alaryngeal voice. If the tone of the pharyngoesophageal segment is too low, the resulting voice will be weak and breathy, or a coarse whisper.

To improve vocal quality for this group of patients, a small pneumatic sound source incorporated into a regular tracheoesophageal shunt valve was designed.

This paper describes experience with such a device. Unfortunately, the sound-producing voice prosthesis is prone to impediment by tracheal secretions.

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References
2 Van der Torn M, Verdonck-de Leeuw IM, Festen JM, De Vries MP, Mahieu HF. Female-pitched sound-producing voice prostheses – initial experimental and clinical results. *Eur Arch Otorhinolaryngol* 2001;258:397–405


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