Aerodynamics of the Pseudo-Glottis

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Key Words

Aerodynamics · Laryngectomy · Tracheo-esophageal voice · Pseudo-glottis

Abstract

Objective: The aim of this work is to study the hitherto unclear aerodynamic parameters of the pseudo-glottis following total laryngectomy. These parameters include airflow rate, sub-pseudo-glottic pressure (SubPsG), efficiency and resistance, as well as sound pressure level (SPL). **Patients and Methods:** Eighteen male patients who have undergone total laryngectomy, with an age range from 54 to 72 years, were investigated in this study. All tested patients were fluent esophageal ‘voice’ speakers utilizing tracheo-esophageal prosthesis. The airflow rate, SubPsG and SPL were measured. **Results:** The results showed that the mean value of the airflow rate was 53 ml/s, the SubPsG pressure was 13 cm H₂O, while the SPL was 66 dB. The normative data obtained from the true glottis in healthy age-matched subjects are 89 ml/s, 7.9 cm H₂O and 70 dB, respectively. Other aerodynamic indices were calculated and compared to the data obtained from the true glottis. **Conclusion:** Such a comparison of the pseudo-glottic aerodynamic data to the data of the true glottis gives an insight into the mechanism of action of the pseudo-glottis. The data obtained suggests possible clinical applications in pseudo-voice training.

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Introduction

Aerodynamics of voice production at the glottis includes airflow rate variation and pressure changes occurring in and around the glottis. These changes were thoroughly studied over a period of time [1, 2, 3]. The accumulated information from such studies enriched the understanding of the aerodynamic events occurring at the glottis during voice production [4]. These aerodynamic studies also have some clinical applications, especially in the assessment of glottal hyperfunction and glottic gaps. More specifically, these studies have an important diagnostic role in each patient’s follow-up assessment following behavioral modification therapy and surgical reduction of a glottic gap.

The pseudo-glottis (neo-glottis), which is created after total laryngectomy, is made by the pharyngo-esophageal (PE) segment and its lining mucosa. The pseudo-glottis is constructed by fibers of the repaired cricopharyngeal, thyropharyngeal and the upper esophageal sphincter muscles. The vibrating lining mucosa of this site remains, however, to be the more important element in the functional outcome of the pseudo-glottis. The muscular element, whatever it might be (cricopharyngeus [5, 6, 7], thyropharyngeus [8] or both [9, 10, 11]), is offering resistance to the air flow in order to build up sub-pseudo pressure to allow the lining mucosa to vibrate (fig. 1). This pseudo-glottis is located opposite the 5th and 6th cervical vertebrae [12].

The pseudo-glottis is the site of production of esophageal 'voice', whether aided or unaided. The aided esophageal voice, commonly referred to as tracheo-esophageal voice, is a result of diverting pulmonary air into the upper esophagus through a tracheo-esophageal shunt/prosthesis. When the air pressure within the upper esophagus is of sufficient magnitude to overcome the resistance of the PE segment this air rushes out through the segment setting the mucosa lining the segment into vibrations. On the other hand, the unaided esophageal voice is produced by injecting oropharyngeal air into the upper esophagus, using it as a temporary reservoir. The air is then expelled upwards and is utilized in 'voice' production in a similar mechanism.

The aerodynamics of the tracheo-esophageal prosthesis has been widely studied with a remarkable improvement in the mechanics of the prosthesis [13, 14, 15]. The improvement in the prostheses has helped secure ample flow of air, under relatively low pressure, into the upper esophagus. This will ultimately improve 'voice' production at the pseudo-glottis. The aerodynamics of the pseudo-glottis, however, was studied in only few investigations [16, 17, 18]. More information about the aerodynamic phenomena at the pseudo-glottis may help the clinician modify the 'vocal' output of the patient during training.

The aim of this work is to study pressure and airflow changes at the pseudo-glottis in order to highlight the mechanism of 'voice' production at this source and to elucidate possible clinical implications on the final rehabilitation of esophageal voice.

Material and Methods

The aerodynamics of the pseudo-glottis were studied in 18 male patients with total laryngectomy for T3 or T4 carcinoma of the larynx. The age of the patients ranged from 54 to 72 years. The predominant male gender in this material reflects the general epidemiological trend of carcinoma of the larynx in our country. Pharyngeal repair was secured by double-layered straight vertical midline sutures, with lax approximation of the inferior constrictor muscle. Primary tracheo-esophageal puncture was performed for voice rehabilitation in only 3 patients, while secondary tracheo-esophageal puncture was performed 3 months after the total laryngectomy in 15 patients. All patients used low-pressure voice prosthesis of the same type (Provox voice prosthesis). None of the patients included in this study received radiotherapy. None had been subjected to preventive or curative treatments of spasms and pharyngeal hypertonicity. All patients were fluent esophageal 'voice' speakers using their tracheo-esophageal puncture and voice prosthesis. They produced speech without effort and with excellent overall intelligibility (grade 4

Fig. 1. a Endoscopic still picture of the pharyngo-esophageal segment at rest. **b** Serial stroboscopic pictures of the vibrations of the mucous membrane surrounding the pseudo-glottis at the PE segment during production of esophageal 'voice': 1 (closed) proceeds to 10 (closed again). Notice a long closed phase from 5–10. This picture illustrates the movement of the mucosal lining of the pseudo-glottis. Such vibrations, which are the bases for sound production at this site, were suggested by Moon and Weinberg [16] to be the result of an aerodynamic-myoelastic phenomenon.

out of a 4-point scale according to our clinic's protocol of assessment). The maximum phonation time of the sustained vowel /a/ was comparable to that of the normal average laryngeal voice [19]. None of the patients required speech or voice therapy, apart from a simple explanation about how to use the new voice prosthesis.

The aerodynamic measurements were made 4–18 months after the total laryngectomy. A speech and voice aerodynamics measuring system (Perci-Sars) was used to measure the oral airflow and the sub-pseudo-glottic pressure (SubPsG). The oral airflow was collected by a pediatric-size face mask fitted tightly around the mouth only. None of the patients had any sign of velopharyngeal incompetence. The mask was connected to the flow

Table 1. Comparison between aerodynamic values obtained by the pseudo-glottis and those obtained by the true glottis

	Pseudo-glottis (means $\pm$ SD)	Range	True glottis ^a (means)	t values	p values
Pressure, cm H ₂ O	13 $\pm$ 6	6–25	7.9	2.4	0.012*
Airflow rate, ml/s	53 $\pm$ 11	34–74	89	10.1	0.000**
SPL, dB	66 $\pm$ 3	61–70	70	1.3	0.078
Glottal efficiency ($\times 10^{-5}$)	133 $\pm$ 62	39–218	133	1.1	0.341
Glottal resistance, cm H ₂ O/l/s	237 $\pm$ 94	102–403	123	9.1	0.001**

* p value is significant; ** p value is highly significant. ^a Kotby et al. [22].

Table 2. Showing the result of Pearson's correlations (r values) among the parameters studied

	SubPsG pressure	Airflow rate	SPL
SubPsG pressure	–	0.526*	–0.214
		0.025	0.394
Airflow rate		–	–0.282
			0.257
SPL			–

* p = 0.05, two-tailed.

meter input of the apparatus. The SubPsG pressure was measured by a tube, with an inside diameter of 3 mm and an outside diameter of 4.1 mm, passed through the nasal cavity and introduced into the upper esophagus, and secured at a distance of 15 cm from the upper central incisors. Fine adjustment of the placement of the position of the lower end of this tube was performed till maximal values of the pressure on attempted esophageal voice production were attained. The other end of the tube was connected to the oral pressure input of the apparatus.

The SPL was measured using a high quality microphone (Shure prologue, dynamic microphone) placed at a distance of 15 cm from the lips, connected to the Kay Elemetrics Visi-pitch II, model 3300.

The data were collected while the patient was producing a sustained vowel / α / production. The average of 3 trials was calculated. This experimental set-up is believed to produce the least disturbance of the vocal tract of the patient, so the results reflect what actually happens in spontaneous connected speech.

Airflow rate data in ml/s, pressure in cm H₂O and SPL in dB were used to calculate the aerodynamic indices of the pseudo-glottis, according to the equations of Van den Berg [20] for glottal efficiency and Broad [21] for glottal resistance.

The pseudo-glottis aerodynamic parameters obtained were compared to data collected from the true glottis of normal age-

matched subjects utilizing the Nagashima PS-77 Phonatory Function Analyzer [22].

The numerical values obtained were analyzed using the SPSS program, version 15, to obtain means, standard deviations and ranges of the parameters. Comparison between such parameters and those obtained from the true glottis was carried out using Student's t test. Correlations between the basic aerodynamic parameters at the pseudo-glottis were assessed using Pearson's correlation.

Results

Table 1 shows the values obtained for SubPsG pressure, airflow rate and SPL, as well as the indices calculated from them: namely, glottal efficiency and glottal resistance. The average sub-pseudo-glottic pressure (SubPsG) as registered from the 18 patients was 13 $\pm$ 6 cm H₂O. The average airflow rate value was 53 $\pm$ 11 ml/s and the average sound pressure level (intensity) was 66 $\pm$ 3 dB. Table 1 also shows the statistical difference between the values obtained from the pseudo-glottis in this study versus those obtained from the true glottis in an earlier study [22].

The pressure and resistance of the pseudo-glottis were significantly higher than the corresponding values of the true glottis. The air flow values of the pseudo-glottis were significantly lower than those of the true glottis. SPL, as well as efficiency values obtained by the pseudo-glottis, were not significantly different from those obtained from the true glottis.

Correlation between the parameters obtained showed a positive significant correlation between the SubPsG pressure and airflow rate ($r = 0.5$, $p = 0.025$), while a non-significant correlation was obtained between SubPsG pressure and SPL. A similarly non-significant correlation was obtained between SPL and airflow rate (table 2).

Discussion

Aerodynamic studies of the glottis are prone to showing differences among investigators [3]. These variations may result from differences in the experimental designs among researchers. The numerical values in this study on the pseudo-glottis have a similar tendency to show such differences when comparing some of our values to those of Moon and Weinberg [16], Schutte and Nieboer [17] and Grolman et al. [18]. Moon and Weinberg [16] studied trans-source flow rates, source driving pressures and resistance in only 5 tracheo-esophageal speakers. On the average, their results for pressure and resistance (ranging from 18 to 49 cm H₂O for pressure, and from 142 to 383 cm H₂O/l/s for resistance) are similar to ours. Their values for airflow rate of 74–336 ml/s were higher than ours. Schutte and Nieboer [17] measured aerodynamic values in 18 tracheo-esophageal speakers. The average sub-pseudo-glottic pressure of their subjects was 4.5 kPa, trans-pseudo-glottic flow was 131 ml/s and glottal efficiency was 0.190×10^{-5} . Grolman et al. [18] reported aerodynamic values from 8 tracheo-esophageal speakers. Their average values of pressure and resistance (22 cm H₂O, 198 cm H₂O/l/s, respectively) were similar to our values. The airflow rate values (167 ml/s) were higher than ours, while their glottal efficiency values (2.2×10^{-5}) were lower than our values.

The low values of the airflow rate at the pseudo-glottis may be explained by the limited supply of air from the trachea through the narrow tracheo-esophageal prosthesis. The high value of the SubPsG pressure in comparison to the true glottis may be a compensation to the lack of available air at the sub-pseudo-glottis. The increased SubPsG pressure may be also due to the higher resistance of the pseudo-glottis.

The wide excursion of the movement of the vibrating mucosa at the pseudo-glottis seen in figure 1 may reflect on the obtained aerodynamic indices in this study. The sheer weight of the vibrating redundant mucosa may increase the resistance of the pseudo-glottis. Furthermore, the mucosa bordering the pseudo-glottis at the PE segment does not have the layered structure of the vocal fold like the true glottis. The lack of the mechanical advantage of the layered structure may offer more resistance at the pseudo-glottis. In addition, the tone of the surrounding muscles bordering the PE junction as well as the post-operative fibrosis may contribute to the increase in the resistance of the pseudo-glottis. This post-operative status varies among laryngectomy patients [23]. All the previously mentioned factors may explain the increased re-

sistance of the pseudo-glottis as compared to the true glottis.

The definition of glottal efficiency varies among different studies [3]. Thus, no conclusion can be drawn from the values of the efficiency as obtained in this study. Accordingly, glottal efficiency values should be taken critically, and are not to be regarded as a dependable index in aerodynamics of the pseudo-glottis.

The pseudo-glottis showed a similar tendency to the true glottis regarding the significant correlation between the airflow rate and SubPsG pressure. Contrary to the true glottis, the SPL does not correlate significantly to those 2 aerodynamic values. This might be explained by the fact that the pseudo-glottis does not represent an effective sound-producing source.

In the light of the results of this study, it might be beneficial for the rehabilitation of the pseudo-glottic 'voice' to use abdomino-diaphragmatic breathing exercises to improve the expiratory support, which may enhance the airflow at the pseudo-glottis and produce a 'voice' with better quality. Such a clinical therapeutic proposal needs verification by a side study to evaluate the impact and mechanism of abdomino-diaphragmatic breath support on the quality of the tracheo-esophageal voice. Furthermore, tight thumb closure of the tracheostoma to avoid any unnecessary escape of air, and to direct most of the air to the shunt to be utilized as an increased air flow by the pseudo-glottis, may help a better production of that 'voice'. The tight closure of the stoma need not be associated with a backward pressure that might obstruct the upper esophagus and jeopardize the passage of air to the pseudo-glottis. A tracheal stomal valve (hands-free device), though more expensive, may be a better alternative for closure of the stoma during speech production.

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