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Main Article

Effect of primary neopharyngeal repair on acoustic characteristics of tracheoesophageal voice after total laryngectomy

O A Albirmawy, A S El-Guindy, M N Elsheikh, M E Saafan, M E Darwish

Abstract

Objectives: The tracheoesophageal puncture technique of voice restoration enables successful voice rehabilitation after total laryngectomy. Because post-operative voice quality can vary significantly, depending on which type of hypopharyngeal repair is chosen, the aim of this study was to evaluate the effect of such repair on tracheoesophageal puncture voice after total laryngectomy.

Study design: Prospective, clinical study.

Setting: Otolaryngology department, Tanta University, Egypt.

Methods: Tracheoesophageal puncture voice was quantitatively and qualitatively evaluated in 40 patients using a Provox 2™ prosthesis after standard total laryngectomy. The patients were divided, according to the type of hypopharyngeal repair, into four groups of 10 cases each, as follows: group one, pharyngoesophageal myotomy; group two, pharyngeal plexus neurectomy; group three, non-muscle vertical repair; and group four, transverse repair. These surgical groups were compared with each other with respect to different voice parameters.

Results: Patient profiles were almost equivalent in all surgical groups. The mean values of most of the parameters of quantitative tracheoesophageal puncture voice did not differ significantly, comparing the four surgical groups; however, a slightly significant difference was observed regarding loud intensity in the non-muscle repair group, and soft and loud jitter in the transverse repair group. Mean values for qualitative measures of intelligibility and communicative effectiveness did not show significant difference. However, a slightly significant difference was observed regarding fluency, word correctness, speaking rate and wetness, with higher values for all these parameters except wetness in the myotomy group, and higher values for wetness in the non-muscle repair group.

Conclusion: The four hypopharyngeal repair types – primary pharyngoesophageal myotomy, pharyngeal plexus neurectomy, non-muscle vertical repair and transverse hypopharyngeal repair – were almost equivalent in prevention of pharyngoesophageal spasm in total laryngectomy patients who had undergone primary tracheoesophageal puncture for voice restoration.

Key words: Laryngectomy; Voice; Larynx Neoplasms

Introduction

Total laryngectomy is a functionally destructive procedure which affects respiration, voice and swallowing. Rapid re-establishment of acceptable, fluent and intelligible speech is critical to the successful psychosocial adjustment of the patient.[1]

Historically, alaryngeal oesophageal voice has been the method of choice. However, only a small percentage of laryngectomees acquired effective voice, compared with presurgical communication parameters, despite months of therapy and practice. The electrolarynx devices subsequently used enabled relatively intelligible communication. However, drawbacks included the mechanical quality of the (unnatural) voice, the need for good dexterity, ongoing costs and user self-consciousness.[2]

Secondary endoscopic tracheoesophageal puncture was used initially for laryngectomised individuals who failed to develop oesophageal speech or refused the use of an artificial larynx.[3] The investigators further advanced this method by incorporating tracheoesophageal puncture at the time of laryngectomy, a method widely termed primary tracheoesophageal puncture.[4–6]

Edels[7] produced a tabular format for comparison of laryngeal and oesophageal speech. If that same table is extended to tracheoesophageal puncture speech, it can be seen that the advantage of such speech over

From the Department of Otolaryngology-Head and Neck Surgery, Tanta University, Egypt.
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oesophageal speech is that the lungs are once more acting as a driving source for voice, as with laryngeal speech.

Laryngectomised patients need a tonic pharyngoesophageal segment to provide a vibratory source for tracheoesophageal puncture voice. This hypertonicity varies with operative techniques of pharyngeal repair. Pharyngoesophageal myotomy and plexus neurectomy have been the 'gold standard' for surgical management of the hypopharynx (neopharynx). Other methods such as non-muscle and transverse repairs have also been used effectively. The pharyngeal constrictor muscles are a major concern in tracheoesophageal voice restoration. Prior to the development of tracheoesophageal voice restoration, minimal attention was paid to these muscles and frequently they were used to help secure the pharyngeal closure or were left open.[8] The initial work of Singer and Blom[9] suggested that the pharyngoesophageal segment was not limited to the cricopharyngeus muscle alone, but also included an extended region of both the inferior and middle constrictor muscles, and the upper oesophageal sphincter. In such patients, the goal is not just creation of an intact neopharynx that does not leak. The luminal diameter of this neopharynx should be sufficient to allow for the passage of food bolus, should not be so flaccid as to adversely affect post-operative voice quality, and should allow for either primary or secondary tracheoesophageal voice restoration.[10]

The tracheoesophageal puncture technique and the application of its associated prosthetic valves are not always problem-free.[11] Such problems include: leakage through or around the tracheoesophageal voice prosthesis; immediate or delayed dysphonia; small or large tracheostoma; granuloma formation; excessive stomach gas; excessive tracheostoma mucus; hypotonic or wet voice; and hypersensitive gag or cough.[12]

Patients' post-operative voice quality can vary significantly depending on which type of hypopharyngeal repair is chosen. The aim of this study was therefore to evaluate the effect of such repairs on quantitative and qualitative parameters of tracheoesophageal puncture voice, following total laryngectomy.

Patients and methods

This study was conducted on 40 patients diagnosed as having primary laryngeal cancer stage III and IV, within the otolaryngology department of Tanta University Hospital, Egypt.

Every patient underwent complete history-taking, otolaryngological examination, computed tomography (CT), endoscopy and biopsy for histopathological analysis. Patients underwent pre-operative tracheoesophageal voice assessment, including assessment of: (1) manual dexterity (enabling the patient to clean and maintain their voice prosthesis); (2) visual acuity (enabling self-cleaning of the voice prosthesis); (3) pulmonary function (as most of the patients were heavy smokers); (4) status of articulation and motor speech skills; and (5) exclusion of any neurological and/or psychological instability. Informed consent was obtained.

Total laryngectomy with appropriate neck dissections was performed in the standard fashion. The tracheoesophageal puncture was placed 10 to 15 mm below the cut edge of the posterior tracheal wall. A 14- to 18-Fr Silastic® Foley catheter was passed into the oesophageal lumen. In some patients, the voice prosthesis was placed at the time of laryngectomy and feeding was maintained by a nasogastric tube. The patients were divided, according to the type of pharyngeal repair, into four groups of 10 cases each, as follows: group one, pharyngoesophageal myotomy; group two, pharyngeal plexus neurectomy; group three, non-muscle vertical repair; and group four, transverse repair. Patients were allocated to receive one of these four types of hypopharyngeal repair depending on many considerations, including: each surgeon's experience in neopharyngeal repair; the effect of radical neck dissection on neopharyngeal innervation; and the width of the remaining hypopharyngeal mucosa after laryngectomy (in cases of transverse repair, it was preferable to perform a transverse repair whenever the pyriform fossa was removed, in order to avoid post-operative stenosis).

In cases of neck dissection, neopharyngeal innervation was tested at the same side using a nerve stimulator, after identifying the main trunk of the hypopharyngeal plexus parallel to the origin of the superior thyroid vascular bundle. When ipsilateral constrictors did not contract on nerve stimulation, a dissection neurectomy was considered to have occurred, and the patient was allocated to the neurectomy group. However, if constrictors did contract on nerve stimulation, any other method of repair could be selected, including neurectomy by removing 1 cm of the main nerve trunk.

Each patient underwent a barium swallow examination at seven to 14 days post-operatively. If a fistula was present, the patient was given nil by mouth, and voice prosthesis insertion and speech therapy were delayed. Once adequate healing was demonstrated, a tracheoesophageal prosthesis (the Provox® 2™; ATOS Medical, Hörby, Sweden) of appropriate size was inserted in the tracheoesophageal puncture. The patients were then trained by the speech therapist to occlude the tracheostoma on expiration, forcing air from the lungs into the neopharynx, and to maintain the prosthesis in a clean state.

All patients were assessed either three months post-operatively, in order to observe maximum phonation results after successive sessions of speech therapy, or six months post-operatively after post-operative radiotherapy, in order to avoid observing the effect of radiotherapy on the vibrating tissues. Standardised voice tasks of sustained phonation and speech were used in order to measure both quantitative and qualitative acoustic parameters. Each patient was asked to sustain the vowel/a/at a comfortable pitch and at a conversational loudness level, on a single deep breath for as long as possible, over three successive trials, in order to establish each patient's dynamic range and level of jitter in vocalisation. A one-second sample

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from the middle of the phonation was analysed for these calculations. Patients were then asked to read a standard passage ('Al-Fat-ha', in Arabic, the initial phrases of the *Holy Quoraan*). Finally, patients read 50 words from one of four standardised lists. These lists comprised sets of single-syllable words that were phonetically balanced.

Signal recordings were performed with patients seated in a quiet room. A condenser microphone was positioned approximately 30 cm from the patient's mouth. The speech signal was fed to the microphone amplifier. The acoustic signals were then processed by a pulse code modulator and stored on a video cassette recorder. This technique recorded signals in a digital format identical to that of a compact disc recording. Data acquisition was performed with an analogue-to-digital converter and a digital input–output system on a computer. The analogue-to-digital converter had a resolution of 16 bits, and was accurate to within ±0.0015 per cent of the full screen. All signals were sampled at 44.1 kHz.

Voice samples were analysed for amplitude, dynamic range (difference), shimmer, fundamental frequency, jitter, maximum phonation time, percentage number of pauses, and harmonics to noise ratio. The range, mean and standard deviation of each parameter were calculated for all surgical groups.

A group of three formally trained listeners was selected to evaluate voice quality, using voice alone rather than audio-visual input, in order to avoid the effect of visual cues on the qualitative scores. A standard passage was used to evaluate the following qualitative voice parameters: intelligibility (i.e. capacity to be understood); communicative effectiveness (i.e. ability to communicate easily and clearly); fluency (i.e. ability to speak effortlessly and without interruption); speaking rate (i.e. speed of speech); and wetness. The listeners rated patients from one to 10 on a 10-cm line, with results calculated in millimetres. Listeners then evaluated the word list; scores were rated as absolute number of words correct, out of a total of 50 words.

Statistical analysis was performed using the analysis of variance test to compare groups one, two, three and four, for each quantitative and qualitative parameter.

Results

Patient profiles for the four surgical groups were roughly equivalent (Table I). Patients comprised 38 men and two women, with ages ranging from 42 to 71 years (mean 56.5 years). All patients were treated for advanced squamous cell carcinoma of the larynx and were staged according to the tumour–node–metastasis classification into stage III (60 per cent) or stage IV (40 per cent). Supraglottic lesions represented 50 per cent of total cases, while endolaryngeal (glottic, transglottic or subglottic) lesions represented the other 50 per cent. Tracheoesophageal puncture was performed primarily for all patients followed by insertion of an appropriately sized Provox 2™ prosthesis, either at the time of surgery (16 cases) or seven to 14 days post-operatively once the tracheoesophageal puncture had matured (24 cases). All patients were clinically free of disease, had excellent deglutition and maintained a regular diet at the time of study.

TABLE I

PATIENT PROFILES

Parameter	Group*			
	I	II	III	IV
Age (yr)				
Range	42–69	44–65	45–71	44–60
Mean	54.4	54.2	57.2	52.4
SD	9.47	8.31	11.79	6.73
Sex (*n*)				
Male	9	10	9	10
Female	1		1	
Primary lesion site (*n*)				
Supraglottic	4	4	4	8
Endolarynx	6	6	6	2
Tumour stage (*n*)				
III	6	6	6	6
IV	4	4	4	4
Procedure (*n*)				
Unilateral modified radical neck dissection	4			
Bilateral modified radical neck dissection		2	4	2
Unilateral radical neck dissection	4	6	4	8
Bilateral selective neck dissection	2	2	2	
Radiotherapy (*n*)				
Post-operative	4	2	4	2
Pre-operative	4	6	4	8
None	2	2	2	

*$n = 10$ for all groups. Yr = years; SD = standard deviation

Quantitative voice assessment

Voice intensity, as measured by sound pressure level, was compared for soft and loud speech. All groups demonstrated a dynamic range in their ability to create both soft and loud speech (Table II). The mean intensities for soft speech were 54.33, 56.92, 54.28 and 51.59 dB in groups one, two, three and four, respectively, whereas those for loud speech were 66.04, 71.68, 74.42 and 63.3 dB, respectively. The dynamic ranges for groups one to four, indicated by the difference between soft and loud sound pressure levels, were 11.71, 14.76, 20.13 and 11.71 dB, respectively. Statistically, the difference in the intensity levels for soft speech in the four surgical groups was not significant ($p > 0.05$). However, a slightly significant difference was observed when comparing loud speech intensity levels ($p = 0.02$), with a higher level in the non-muscle repair group. There was no significant difference in dynamic range, comparing the four groups ($p > 0.05$).

Fundamental frequency (i.e. the rate at which the voicing source vibrates) was similarly measured in all patients for soft and loud speech, in cycles per second or hertz (Table III). No statistically significant difference in soft or loud fundamental frequency was observed, comparing the four groups ($p > 0.05$); there were equal mean peaks in the myotomy and neurectomy groups for soft

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TABLE II

RESULTS FOR SOFT AND LOUD INTENSITY, DYNAMIC RANGE AND SHIMMER

Parameter	Group				*p*
	I	II	III	IV	
Soft intensity (dB)					
Range	40.52–61.12	48.82–63.5	45.9–62.18	48.5–56.44	
Mean	54.33	56.92	54.28	51.59	>0.05
SD	8.43	7.26	7.33	3.14	
Loud intensity (dB)					
Range	58.33–72.43	63.17–77.2	66.71–78.19	55.16–70.85	
Mean	66.04	71.68	74.42	63.3	0.02
SD	5.8	5.6	4.6	6.55	
Dynamic range (dB)					
Range	9.18–17.81	11.63–20.3	15.58–25.87	6.66–18.51	
Mean	11.71	14.76	20.13	11.71	>0.05
SD	3.51	3.26	4.36	4.65	
Shimmer (dB)					
Range	0.7–1.82	0.77–1.2	0.79–1.3	0.91–1.9	
Mean	1.19	0.93	1.02	1.21	>0.05
SD	0.56	0.17	0.21	0.41	

SD = standard deviation

fundamental frequency, and a higher peak in the neurectomy group for loud fundamental frequency.

Amplitude perturbation (i.e. shimmer) and frequency perturbation (i.e. jitter) are small cycle-to-cycle differences in intensity and frequency, respectively. They are a reflection of fine motor control of the phonatory mechanism. Shimmer (in dB) was evaluated for each patient, for loud speech only (Table II); the difference between the four groups was not significant ($p > 0.05$), although levels were higher in the transverse repair group. Jitter (in per cent) was evaluated in all patients for both soft and loud speech (Table III); a slightly statistically significant difference was observed ($p = 0.04$ and 0.03, for soft and loud speech respectively), with a peak in the transverse repair group.

Temporal measures, including maximum phonation time in seconds, percentage number of pauses, and harmonics to noise ratio (periodic to aperiodic ratio) in dB, were investigated in all patient groups (Table IV). Periodicity (harmonics) is defined as any cyclical waveform which is repeated consecutively, whereas aperiodicity (noise) is random waveform patterns. Silence is indicated by a return to the baseline. Maximum phonation time is the amount of time that speakers can sustain vowel phonations. Statistically, no significant difference was found between the four groups for any parameter ($p > 0.05$), although peaks were observed in the neurectomy, non-muscle repair and myotomy groups for maximum phonation time, percentage number of pauses, and harmonics to noise ratio, respectively.

Qualitative voice assessment

Qualitative voice was evaluated using the parameters of intelligibility, communicative effectiveness, fluency, word correctness, speaking rate and wetness. Results for these qualitative parameters are summarised in

TABLE III

RESULTS FOR SOFT AND LOUD FUNDAMENTAL FREQUENCY AND JITTER

Parameter	Group				*p*
	I	II	III	IV	
Soft F_0 (Hz)					
Range	71.33–86.17	77.71–83.15	75.5–81.61	72.13–85.01	
Mean	80.81	80.81	79.004	78.76	>0.05
SD	7.01	2.18	2.26	5.09	
Soft jitter (%)					
Range	2.68–3.62	2.95–4.02	3.15–4.03	3.33–5.19	
Mean	3.12	3.45	3.53	4.1	0.04
SD	0.33	0.51	0.41	0.67	
Loud F_0 (Hz)					
Range	129.56–139.16	130.64–139.95	129.9–138.28	128.88–139.01	
Mean	134.52	134.61	133.23	133.33	>0.05
SD	3.71	3.84	3.56	4.23	
Loud jitter (%)					
Range	3.27–4.07	3.77–4.86	3.85–4.85	4.26–5.95	
Mean	3.82	4.16	4.22	4.82	0.03
SD	0.32	0.42	0.38	0.7	

F_0 = fundamental frequency; SD = standard deviation

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TABLE IV

RESULTS FOR QUANTITATIVE TEMPORAL VOICE PARAMETERS

Parameter	Group				p
	I	II	III	IV	
Max phonation time (s)					
Range	7.8–12.8	8–16.9	8.9–15.3	8.9–14.3	
Mean	9.86	11.68	11.52	11.26	>0.05
SD	1.88	3.40	2.56	2.37	
No of pauses (%)					
Range	7–13.4	6–11	6.4–12.9	6–10	
Mean	8.86	8.54	9.92	8.46	>0.05
SD	2.60	1.99	2.42	1.70	
Harmonics to noise ratio (dB)					
Range	−2.19 to −1.13	−2.22 to −1.55	−2.5 to −1.89	−2.02 to −0.99	
Mean	−1.86	−1.94	−2.05	−1.98	>0.05
SD	0.42	0.24	0.25	0.44	

Max = maximum; s = seconds; SD = standard deviation; No = number

Table V. No statistically significant differences were observed in intelligibility and communicative effectiveness, comparing the four study groups; the highest mean value for intelligibility was seen in the myotomy group, and that for communicative effectiveness in the myotomy and transverse repair groups. A slightly significant difference was seen for fluency, word correctness, speaking rate and wetness ($p = 0.03$), with best results for fluency, word correctness and speaking rate observed in the myotomy group and the highest wetness observed in the non-muscle repair group.

Discussion

The tracheoesophageal puncture technique for voice restoration, introduced by Singer and Blom in 1980,[3] is a successful method of providing voice rehabilitation after total laryngectomy. These authors noted that voice restoration could be limited by pharyngeal constrictor muscle spasm. Subsequent efforts were centred on pharyngeal repair technique modifications, and adjuvant procedures were performed in the primary setting to prevent voice-limiting spasm.

In the current series, tracheoesophageal puncture voice was quantitatively and qualitatively evaluated in 40 patients who had undergone standard total laryngectomy. Patients were categorised, according to the type of hypopharyngeal repair, into four groups, as follows: group one, vertical repair with pharyngoesophageal myotomy; group two, vertical repair with unilateral pharyngeal plexus neurectomy; group three, non-muscle vertical repair; and group four, transverse repair. The groups were compared with each other as

TABLE V

RESULTS FOR QUALITATIVE VOICE PARAMETERS

Parameter	Group				p
	I	II	III	IV	
Intelligibility score (mm)*					
Range	90–93	89–91	89–92	88–91	
Mean	91.2	90.2	90.4	89.6	>0.05
SD	1.30	0.83	1.14	1.14	
Communicative effectiveness score (mm)*					
Range	89–92	88–92	87–90	89–91	
Mean	90.2	90	88.6	90.2	>0.05
SD	1.02	1.58	1.14	0.83	
Fluency score (mm)*					
Range	84–86	82–84	80–82	79–81	
Mean	85	83.4	81.2	80.2	0.03
SD	0.70	0.89	0.83	0.83	
Word correctness score†					
Range	38–41	37–39	38–39	35–37	
Mean	39.4	37.6	36.6	36.2	0.03
SD	1.14	0.89	0.54	0.83	
Speaking rate score (mm)*					
Range	77–79	74–76	75–78	71–74	
Mean	78.2	75	76.6	72.6	0.03
SD	0.83	0.70	1.14	1.14	
Wetness score (mm)*					
Range	14–16	16–18	17–19	14–15	
Mean	15.2	17.2	18.4	14.6	0.03
SD	0.83	0.83	0.89	0.54	

*Out of 100 mm; †out of 50 words.

regards different voice parameters, within a prospective, clinical trial, in order to evaluate the best method of hypopharyngeal repair.

Voice restoration was performed primarily in all cases. According to Blom,[13] the technique of primary surgical voice restoration offers the surgeon and patient several advantages, namely: (1) it is simple, effective and quick; (2) it has relatively low morbidity; (3) it is cost-effective as it eliminates a secondary procedure for voice restoration and reduces prolonged speech therapy sessions; (4) the tracheoesophageal puncture site provides an avenue for post-operative enteral nutrition, eliminating the need for a nasogastric tube; and (5) early voice production gives the patient a psychological boost, which although intangible undoubtedly improves convalescence.

Assessment of quantitative results for the four surgical groups did not reveal any significant differences for most of the voice parameters; thus, it is considered that all pharyngeal repair types studied succeeded in preventing post-operative pharyngospasm. These results are consistent with those of Yoshida *et al.*,[14] who concluded that pharyngeal constrictor myotomy successfully resolved pharyngoesophageal hypertonicity and achieved successful tracheoesophageal speech in 85 per cent of their cases.

The pharyngeal plexus neurectomy reported by Singer *et al.*[15] was performed in the primary setting. According to their report, failure in some cases occurred because of incomplete identification and resection of all branches in the plexus. They considered the primary pharyngeal neurectomy to be highly effective in preventing spasm or hypertonicity, and to produce significantly higher voice fundamental frequencies, possibly due to the residual resting tension of the upper oesophageal sphincter or pharyngoesophageal segment. In the current series, neurectomy group patients developed no post-operative fistulae or pharyngospasm, and their average soft and loud fundamental frequencies (80.81 and 134.61 Hz, respectively) were slightly higher than those recorded in other groups, but not significantly so.

Clevens *et al.*[16] reported performing myotomy automatically at laryngectomy if the constrictors were not sutured together (non-muscle closure). They reported 100 per cent success in 21 patients with primary voice restoration; however, their fistula rate was 9.5 per cent, almost double that of the three-layer technique with muscle closure (5 per cent). Deschler *et al.*[17] reported using the half muscle technique on pharyngeal closure, in an attempt to ensure the benefits of both methods while limiting the drawbacks of each. The fistula rate for this technique was acceptably low, at 4 per cent. Because no further incisions or compromise of mucosal integrity is needed, as with the primary myotomy procedure, the risk of fistula formation for the half-muscle closure group may be less than with primary myotomy. Because only one constrictor muscle flap is used for reinforcement, a circumferential muscular ring that may go into spasm is not created. Twenty-two of 23 patients were able to achieve a functional voice, for a 96 per cent success rate. This compares favourably with the 84 and 90 per cent success rates reported with primary myotomy and plexus neurectomy techniques, respectively.[14,15] A completely patulous conduit (as can occur when no muscle closure is used) was also avoided. In the non-muscle repair group of this current study, non-muscle closure was performed in 10 patients. All patients demonstrated no fistula formation or post-operative pharyngospasm. The soft voice intensities and frequencies and loud voice frequencies were consistent with those of other groups, without significant differences, while the loud speech intensity was significantly greater compared with other groups. In comparison with posterior myotomy as classically described by Hamaker *et al.*,[4] a non-muscle anterior closure did not affect the status of the upper oesophageal sphincter just below the repaired neopharynx and above the tracheoesophageal puncture, preserving its tonicity for proper vibration and voicing.

According to Hamaker and Cheesman,[18] most wide-field laryngectomies allow for horizontal closure of the mucosa and constrictor muscles, unless there is resection of the pyriform sinus. Ten patients undergoing surgery which included horizontal closure of the mucosa, submucosa and constrictors were 100 per cent successful in establishing voice. However, the majority of these patients were hypotonic, requiring external neck strap compression to improve their voice volume. In the current series, transverse pharyngeal repair was performed in group four patients, and their voices were considered somewhat hypotonic in comparison with other groups; their mean soft intensity was 51.59 dB, loud intensity 63.3 dB and dynamic range 11.71 dB, and they had a slightly higher level of shimmer (1.21 dB). Their fundamental frequency for soft speech was 78.76 Hz and for loud speech was 133.33 Hz. Statistically, no significant difference was observed, except for the loud intensity parameter.

Blood[19] measured the fundamental frequency in 10 tracheoesophageal, 10 oesophageal and 10 laryngeal speakers. Tracheoesophageal speakers had a mean fundamental frequency of 89.3 Hz, which was significantly lower than that of the laryngeal group (approximately 121 Hz) but significantly higher than that of the oesophageal group (approximately 64 Hz). In the current study, the mean fundamental frequency levels for surgical groups one, two, three and four during soft speech were 80.81, 80.81, 79.0 and 78.76 Hz, respectively. However, these groups' mean fundamental frequencies during loud phonation were 134.52, 134.61, 133.23 and 133.33 Hz, respectively. The mean values for soft speech fundamental frequency in the current study groups were consistent with those reported by Blood,[19] Robbins *et al.*,[20] and Qi and Weinberg;[21] however, our patients' average loud speech fundamental frequency was even higher than that of Blood's[19] laryngeal group patients.

A number of comparative acoustic studies have been performed to investigate the effect of pulmonary air supply on the amplitude of tracheoesophageal puncture voice signal. Blood[19] found that tracheoesophageal puncture speakers had a mean voice intensity of 80 dB sound pressure level. This was significantly greater than that of oesophageal speakers (approximately 72 dB sound pressure level), but did not differ significantly from that of laryngeal speakers (approximately 84 dB sound pressure level). The tracheoesophageal puncture speakers in Robbins and colleagues'[20] study had an approximately 10 dB greater voice intensity compared with laryngeal speakers. These authors surmised that the increased closure time, combined with increased exhalatory airflow (from the pulmonary air supply) and greater subneoglottic pressure (associated with higher resistance of the pharyngoesophageal segment), resulted in higher mean intensity levels in tracheoesophageal speech. In the current study, both soft and loud speech intensity measures showed lower mean values compared with TEP speakers of Blood[19] and Robbins and Colleagues.[20]

Robbins *et al.*[20] measured perturbations in their comparative study during sustained phonation. Tracheoesophageal puncture speakers demonstrated a jitter of 5.14 per cent and a mean shimmer of 0.8 dB sound pressure level. All perturbation measures were greater in tracheoesophageal puncture speakers compared with laryngeal speakers, and less compared with oesophageal speakers. In the current series, all surgical groups showed lower values for both soft and loud jitter than those obtained by Robbins *et al.*[20] and by Pindzola and Cain.[22] This may be explained by the effect of different types of primary hypopharyngeal repair on adjustment of neoglottal neuromuscular coordination and on production of fine tracheoesophageal speech. Shimmer values observed in the current study were approximately consistent with those reported in the literature.

Temporal measures, including maximum phonation time and percentages of periodicity (i.e. harmonics), aperiodicity (i.e. noise) and silence (i.e. pause), have been investigated in alaryngeal populations in the comparative studies of Robbins *et al.*[20], Pindzola and Cain[22], and Baggs and Pine.[23] Robbins *et al.*[20] found that tracheoesophageal speakers had 77.7 per cent periodicity, 11.8 per cent aperiodicity and 10.5 per cent silence in their speech signals; this distribution was similar to that of laryngeal control subjects, but represented significantly more periodicity compared with oesophageal speakers. In our study, maximum phonation time was highest in the neurectomy group (11.68 seconds) and lowest in the myotomy group (9.86 seconds), without any significant difference with other groups. The highest percentage number of pauses (9.92 per cent) was observed in the non-muscle repair group. Instead of percentage periodicity and percentage aperiodicity, the harmonics to noise ratio (in dB) was evaluated in the present study; best values were observed in the myotomy group, but this difference was insignificant.

- **The tracheoesophageal puncture technique is a successful way of providing voice rehabilitation after total laryngectomy**
- **This study evaluated voice quality following laryngectomy procedures in which four different methods of pharyngeal repair were used**
- **Primary pharyngoesophageal myotomy, pharyngeal plexus neurectomy, non-muscle repair and transverse hypopharyngeal repair were almost equally effective in preventing pharyngospasm in total laryngectomy patients who had undergone primary tracheoesophageal puncture for voice restoration**

The various published reviews of tracheoesophageal speech have not used any standardised pattern of qualitative voice analysis. Various listeners, including speech pathologists, surgeons, naïve listeners and combinations of these, assessed voice using limited and varying criteria.[24] In the current series, successful functional voice restoration was achieved in all patients; furthermore, thorough, qualitative, listener assessment of patient voice function was undertaken in order to investigate the effects of different methods of primary neopharyngeal repair. The present study used only trained listeners, in order to assess and evaluate patients' voices in a standardised manner. We saw no need for naïve listeners, the use of whom would have required additional, multiple statistical comparisons. Six parameters were chosen which were felt to adequately and specifically assess voice and tracheoesophageal speech. Our three trained listeners' individual measurements showed a high level of inter-observer agreement. No statistically significant differences were observed when comparing the four surgery groups regarding intelligibility and communicative effectiveness. Slightly significant differences were observed regarding fluency, word correctness, speaking rate and wetness. The myotomy group showed the best qualitative voice results for all parameters save wetness, which was greatest in the non-muscle repair group and least in the transverse repair group. These results agree with qualitative tracheoesophageal voice findings for standard laryngectomised groups as reported by Blom *et al.*,[8] Deschler *et al.*[24] and Medina *et al.*[25]

Conclusion

Primary pharyngoesophageal myotomy, pharyngeal plexus neurectomy, non-muscle repair and transverse hypopharyngeal repair were almost equally effective in preventing pharyngospasm in total laryngectomy patients who had undergone primary tracheoesophageal puncture for voice restoration. The myotomised surgical group had the highest mean values for all qualitative voice parameters except wetness. The

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slightly greater soft speech intensity, loud speech fundamental frequency and maximum phonation time observed in patients with pharyngeal plexus neurectomy may have resulted from residual resting tension in the pharyngoesophageal segment. The voices of non-muscle repair group patients were considered wet when compared with other surgical groups; these patients had a slightly greater loud speech intensity compared with others. Tracheoesophageal puncture voice after transverse repair of the hypopharynx was considered hypotonic but not significantly so.

Further studies with larger patient numbers are recommended in order to enable better statistical evaluation.

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Address for correspondence:
Dr Osama Amin Albirmawy,
88 Reyad St,
Tanta 31211,
Gharbeya, Egypt.

E-mail: albirmawy@hotmail.com

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