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MAIN ARTICLE

Voice function following Han's uvulopalatopharyngoplasty

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Abstract

Objective: To investigate voice function following Han's uvulopalatopharyngoplasty.

Patients and methods: Acoustic and articulatory function was examined by acoustic analysis and by formant frequency and bandwidth analysis, before and after Han's uvulopalatopharyngoplasty, in 56 patients with obstructive sleep apnoea hypopnoea syndrome.

Results: These patients' normalised noise energy was higher than normal, and improved post-operatively. Their pre-operative F_1, F_2, and F_3 formant frequencies and B_1 and B_2 formant bandwidths were significantly lower than those of normal controls; however, one month after surgery their F_1 and F_2 frequencies were markedly higher.

Conclusion: The acoustic and articulatory characteristics of obstructive sleep apnoea hypopnoea syndrome patients differed from those of normal subjects. After Han's uvulopalatopharyngoplasty, obstructive factors in the oropharynx were relieved, allowing oropharyngeal cavity expansion and a gradual increase in formant frequency to within the normal range. Patients' vocal quality improved and their resonator and articulator functions were protected and enhanced.

Key words: Sleep Apnea, Obstructive; Surgery; Speech; Acoustics

Introduction

The production of speech depends on the integration of the activator, vibrator, resonator and articulator organs and the central nervous system. Although vocal sounds are produced in the larynx, this generates only the raw acoustic elements of speech, which must be modified and shaped by the vocal tract. The oral cavity, lips, soft palate and tongue play an important role in resonance and articulation.

The majority of obstructive sleep apnoea hypopnoea syndrome patients have structural abnormalities in the upper airway (e.g. a thickened and slack soft palate, thickened pharyngeal wall, hypertrophic tonsils, and tongue base lymphoproliferation) which lead to structural changes affecting voice resonance and articulation.

Han's uvulopalatopharyngoplasty is a revised version of the classical uvulopalatopharyngoplasty procedure used to treat obstructive sleep apnoea hypopnoea syndrome.[1] The main characteristic of Han's uvulopalatopharyngoplasty is preservation of the uvula, while removal of a large portion of the soft palate. The aim of this procedure is to preserve voice and swallowing function as much as possible.

The current study aimed to investigate the acoustic and articulatory characteristics of obstructive sleep apnoea hypopnoea syndrome patients, before and after Han's uvulopalatopharyngoplasty, in order to understand the characteristics of the resonance cavity and its effect on pronunciation.

Patients and methods

Patient selection

From November 2001 to June 2007, 68 patients (64 men and four women) with obstructive sleep apnoea hypopnoea syndrome were seen in our otolaryngology head and neck surgery department. Their age ranged from 25 to 65 years (mean, 42.5 years). All patients were diagnosed by polysomnography in our sleep centre. Pre-operative examination showed a narrow oropharyngeal cavity with varying degrees of bilateral tonsillar hypertrophy and of hypertrophy and laxity of the soft palate.

Fifty-six patients (53 men and three women) were treated with Han's uvulopalatopharyngoplasty, between June 2005 and June 2007, while 12 patients (11 men and one woman) were treated with classic

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uvulopalatopharyngoplasty, between November 2001 and May 2002. All patients also underwent tonsillectomy at the time of surgery.

Normal subjects

We also recruited a control group of 40 normal subjects (38 men and two women), with ages ranging from 29 to 55 years (mean, 42.3 years). All subjects were interviewed to ensure that they were non-smokers who had no history of sleep apnoea or voice disorders, and who had normal articulation and resonance. None of the controls had ever received any professional training in phonation or singing.

Procedures

All patients underwent surgery under general anaesthesia. Post-operative follow up ranged from one month to five years.

Evaluation of voice function

Following both types of uvulopalatopharyngoplasty, pharyngeal remodelling is known to be complete by approximately one month after surgery, and thereafter does not change over time. Therefore, vocal function was evaluated pre-operatively in both study patients and controls, and then one week to one month post-operatively in patients undergoing Han's uvulopalatopharyngoplasty and one month post-operatively in patients undergoing classical uvulopalatopharyngoplasty.

Evaluation of vocal function included analysis of acoustic and articulatory parameters. In addition, a stroboscopic examination was performed to exclude the presence of laryngeal abnormalities.

Acoustic analysis was performed in a sound-treated room, with the level of environmental noise kept at below 45 dB SPL. All subjects assumed a comfortable position, with a distance of 15 cm between their mouth and the microphone. Mean fundamental frequency, jitter, shimmer, harmonics-to-noise ratio and normalised noise energy were assessed during comfortable, sustained production of the vowel sound /ae/. A stable segment of 1.0 second duration was extracted from the recorded sound samples. The sampling rate was 44 100 Hz. Computer speech laboratory software (Dr Speech version 4; Tiger DRS, Seattle, Washington, USA) was used to process and analyse the data.

The articulatory analysis assessment parameters were the formant frequencies F_1, F_2 and F_3, and the formant bandwidths B_1, B_2 and B_3.

Statistical analysis

The Statistical Package for the Social Sciences for PC version 8.0 software program was used for statistical analysis of data (SPSS Inc, Chicago, Illinois, USA). Results for all groups were tested using one-way analysis of variance.

Results

Some post-operative complications were noted, such as mucosal swelling of the oropharynx, nasal regurgitation, hypernasality and pharyngeal dryness (Figure 1). Mucosal swelling resolved in the first two post-operative weeks. In the Han's uvulopalatopharyngoplasty patients, other complications gradually resolved over three months post-operatively. In the classical uvulopalatopharyngoplasty patients, nasal regurgitation, hypernasality and pharyngeal dryness resolved in the first six months post-operatively in 10 patients, but persisted beyond this time in the remaining two patients.

When we compared the pre-operative acoustic parameters of obstructive sleep apnoea hypopnoea syndrome patients and normal controls, no statistically significant differences were found, except for normalised noise energy which was significantly higher in obstructive sleep apnoea hypopnoea syndrome patients ($p = 0.018$). One week after Han's uvulopalatopharyngoplasty, the normalised noise energy was still significantly higher in obstructive sleep apnoea hypopnoea syndrome patients than in normal controls ($p = 0.001$). However, one month after this procedure, patients' normalised noise energy showed significant improvement ($p = 0.048$) (Table I). One month after surgery, there were no statistically significant differences in any other acoustic parameter, comparing the Han's uvulopalatopharyngoplasty patients and classical uvulopalatopharyngoplasty patients.

Regarding articulatory analysis, we found significantly lower pre-operative results for the formant frequencies F_1, F_2 and F_3 and the formant bandwidths B_1 and B_2 in the obstructive sleep apnoea hypopnoea syndrome patients, compared with normal controls (p values of <0.001, 0.001, 0.017, 0.022 and 0.043, respectively). One week after Han's uvulopalatopharyngoplasty, patients' formant frequencies were not significantly different from their pre-operative results, and their F_1 and F_2 values were still significantly lower than those of normal controls ($p < 0.001$ and $p = 0.004$,

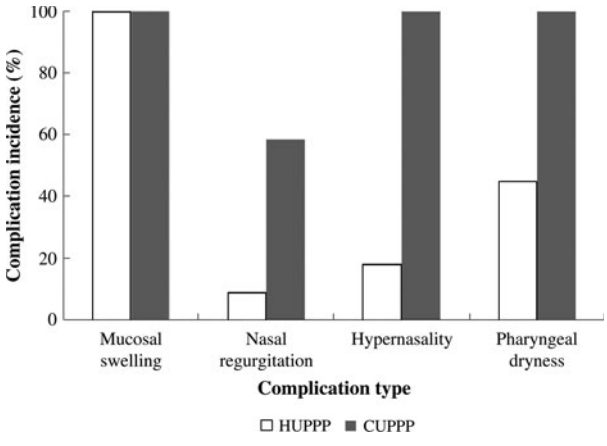

FIG. 1
Incidence of post-operative complications.

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TABLE I
PRE- AND POST-OPERATIVE ACOUSTIC RESULTS

Group	Pts (*n*)	F_0 (Hz)		Jitter (%)		Shimmer (%)		HNR (dB)		NNE (dB)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Pre-op	68	138.63	21.25	0.20	0.05	1.93	0.38	23.05	2.56	−9.92*	2.46
1 wk post-HUPPP	56	133.86	26.01	0.20	0.11	1.87	0.91	22.58	3.76	−9.31†	3.97
1 mth post-HUPPP	56	140.47	28.48	0.21	0.11	1.92	0.04	22.21	2.93	−11.09‡	3.45
1 mth post-CUPPP	12	135.78	23.84	0.20	0.12	1.87	0.14	23.58	3.62	−12.59‡	2.56
Controls	40	139.81	29.05	0.20	0.07	1.88	0.18	23.03	2.85	−12.11	2.23

*$p < 0.05$, †$p < 0.01$, *vs* controls. ‡$p < 0.05$ *vs* pre-operation (pre-op). Pts = patients; F_0 = fundamental frequency; HNR = harmonics-to-noise ratio; NNE = normalised noise energy; SD = standard deviation; wk = week; HUPPP = Han's uvulopalatopharyngoplasty; mth = month; CUPPP = classical uvulopalatopharyngoplasty

respectively). One month after Han's uvulopalatopharyngoplasty, patients' F_1, F_2 and B_2 values were significantly increased, compared with pre-operative values (p values of 0.025, 0.032 and 0.017, respectively). Similarly, one month after classical uvulopalatopharyngoplasty, these patients' F_1, F_2 and B_2 values were also significantly increased compared with pre-operative values (p values of 0.01, 0.049 and 0.014, respectively). When these parameters were compared for one-month post-operative Han's uvulopalatopharyngoplasty patients versus normal controls, there were no statistically significant differences. However, results for the F_3 formant frequency in one-month post-operative classical uvulopalatopharyngoplasty patients were significantly higher, compared with these patients' pre-operative results, with the normal controls' results, and with the one-month post-operative results for Han's uvulopalatopharyngoplasty patients (p values of <0.001, 0.046 and 0.019, respectively) (Table II).

Discussion

During speech, the vocal folds are vibrated by the subglottic airstream, producing the fundamental acoustic elements of the voice. This sound is enhanced by resonator organs (e.g. the pharyngeal cavity, oral cavity, nasal cavity and thoracic cavity), forming various kinds of phonemes. Final speech is then produced as a result of the synegistic effect of the articulators (e.g. the soft palate, mouth, tongue, lips and teeth). The vocal tract (formed by a horn-shaped channel from the vocal folds to the lips) plays the most important role in resonation.

Formants are generated by the interaction between the acoustic frequencies produced by the vocal tract (including the vocal folds) and the various resonators. Formant characteristics are mainly described in terms of frequency and bandwidth. The term frequency refers to the constant frequency in the sound spectral distribution which occurs when a vowel is pronounced, and it is presently an important parameter used to evaluate formants and vowel sound quality. The term bandwidth refers to the bandwidth 3 dB below the peak of the formant, and is determined by the loss of sound wave transmission within the vocal tract; thus, it is an indicator of progression of the formant.

The characteristics of the vowel formant determine the vowel factors of the voice. They represent the resonance characteristics of the vocal tract, and determine the vocal differences between different individuals. When the voice passes through the vocal tract, there are generally four to five formants in operation, the first three of which determine the quality of the vowel.

- **Classical uvulopalatopharyngoplasty is used to treat obstructive sleep apnoea hypopnoea syndrome**
- **It expands the oropharyngeal cavity and affects acoustic and articulatory characteristics**
- **Han's uvulopalatopharyngoplasty is a revised procedure designed to preserve the uvula while removing large portions of the soft palate**
- **In this study, after this revised procedure, oropharyngeal obstruction was relieved and the oropharyngeal cavity expanded, increasing formant frequencies to the normal range**
- **Patients' vocal qualities improved, and their resonator and articulator functions were protected and enhanced**

For example, when pronouncing the vowel /e/, the vocal folds vibrate, the tongue moves slightly forward, the tip of tongue touches the lower gingiva, the soft palate rises, and the lips open and flatten. The formant frequency F_1 directly correlates with the degree of mouth-opening and the level of the tongue (i.e. the higher the tongue level, the lower the F_1 frequency). The F_2 frequency relates to the anteroposterior position of the tongue (i.e. the further back the tongue, the lower the F_2 frequency). The F_3 frequency relates to the decline of the soft palate and closure of the velopharyngeal port (i.e. the lower the soft palate, the lower the F_3 frequency).[2]

Our results showed that the formant frequencies F_1, F_2 and F_3 were lower in obstructive sleep apnoea

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TABLE II
PRE- AND POST-OPERATIVE ARTICULATORY RESULTS

Group	Pts (n)	F_1 Mean	F_1 SD	B_1 Mean	B_1 SD	F_2 Mean	F_2 SD	B_2 Mean	B_2 SD	F_3 Mean	F_3 SD	B_3 Mean	B_3 SD
Pre-op	68	465.72*	93.56	118.36†	23.58	1244.33*	196.37	483.56†	84.59	2280.20†	234.01	823.45	111.42
1 wk post-HUPPP	56	467.85*	101.16	159.81	29.24	1405.77*	678.30	512.24	98.84	2359.69	245.57	884.11	185.88
1 mth post-HUPPP	56	533.68‡	133.25	171.76	14.21	1539.67‡	339.72	562.83‡	58.95	2311.24**	314.62	832.39	177.05
1 mth post-CUPPP	12	554.30‡	80.42	160.53	36.47	1628.9‡	435.96	573.13‡	78.69	3056.83†§	298.83	986.64	192.45
Controls	40	562.26	117.36	191.69	69.82	1700.52	198.57	587.11	73.55	2657.20	203.96	891.28	213.36

*$p < 0.01$, †$p < 0.05$, *vs* controls. ‡$p < 0.05$, §$p < 0.01$, *vs* pre-operation (pre-op). **$p < 0.05$ *vs* 1 month (mth) post classical uvulopalatopharyngoplasty (CUPPP). Pts = patients; F = formant frequency; B = formant bandwidth; SD = standard deviation; wk = week; HUPPP = Han's uvulopalatopharyngoplasty; mth = month

hypopnoea syndrome patients than in controls. This is presumably due to abnormal anatomical structures in the upper airway (e.g. a small oropharyngeal cavity and a hypertrophic, collapsed soft palate) which lead to a significant increase in the contact area of the soft palate and the tongue, and a significant decrease in the angularity of the soft palate and the hard palate. These changes result in a higher and more posterior position of the tongue, and a lower relative position of the soft palate, which cause the F_1, F_2 and F_3 frequencies to decrease. The reduction in the formant bandwidths B_1 and B_2 presumably reflected the loss of sound waves that would normally gradually increase during transmission along the vocal tract.

Uvulopalatopharyngoplasty has been the most common operation performed for obstructive sleep apnoea hypopnoea syndrome since the early 1980s.[3] Serious post-operative complications (including palatopharyngeal incompetence, voice changes, globus sensation and palatopharyngeal stenosis) appear to be uncommon.[4] In order to reduce the complication rate without compromising surgical outcomes, several revised uvulopalatopharyngoplasty procedures have been developed over the past 20 years.[1,5,6]

Han's uvulopalatopharyngoplasty is an effective procedure which produces fewer complications than classical uvulopalatopharyngoplasty. It characteristically enables: complete preservation of the uvula; resection of a larger portion of the soft palate (leaving the levator palati and tensor palati intact); removal of the adipose tissue in the velum palate space; and 'normal' shape and function of the preserved uvula, due to scar tissue contraction on both sides of the palato-uvularis and the lower margin of the tensor palaini.[1] Following Han's uvulopalatopharyngoplasty, our study findings indicate that complications resolve within three months, without compromising the surgical response. However, some of our classical uvulopalatopharyngoplasty patients had obvious nasal regurgitation, hypernasality and pharyngeal dryness which did not resolve.

We found no significant changes in the F_1, F_2 and F_3 formant frequencies one week after Han's uvulopalatopharyngoplasty; this is similar to results reported both by Coleman and Sly and by Rihkanen and Soini.[7,8] Some patients in these authors' studies had undergone tongue base lymphoid tissue resection and/or nasal septum reconstruction. In our own series, early post-operative acoustic assessment found no significant differences in the F_1 and F_2 frequencies, compared with pre-operative values; this was mainly due to local inflammatory exudate, mucosal hyperaemia and post-operative swelling. Tongue swelling also occurred due to depression during surgery. Therefore, for a short post-operative period, the oropharyngeal cavity was still small, with the tongue in a high, posterior position and the soft palate in a depressed position with impaired elevation; thus, the F_1, F_2, F_3 frequencies were low.

One month after Han's uvulopalatopharyngoplasty, the mucosal oedema of the pharynx had resolved, the soft palate was higher, and the relative position of the tongue was lower and more anterior due to soft palate elevation; all of these changes led to an increase in F_1 and F_2. These results matched those of Nakai *et al.*[9] However, an increase in the F_3 frequency was not apparent at this time, possibly because the relevant muscles had not yet resumed the normal maintenance of the soft palate, which thus could not be effectively altered during pronunciation. One month after Han's uvulopalatopharyngoplasty, there was no significant difference in acoustic parameters and the formant parameters F_1, F_2 and B_2, compared with normal controls, suggesting that the obstructive sleep apnoea hypopnoea syndrome patients had achieved an oropharyngeal structure which was close to normal. In comparison, Murry and Bone evaluated the speech function of four obstructive sleep apnoea hypopnoea syndrome patients before and after classical uvulopalatopharyngoplasty, and found no significant difference in F_1 but a significant decrease in F_2; these results do not match those of our study.[10] In addition, we noted that the one-month post-operative F_3 frequency of classical uvulopalatopharyngoplasty patients was significantly higher compared with their pre-operative F_3 frequency, with the Han's uvulopalatopharyngoplasty patients' one-month post-operative F_3, and with the normal controls' F_3. It is possible that classical uvulopalatopharyngoplasty removes excessive soft tissue from the soft palate and uvula, resulting in soft palate over-elevation which affects the resonator and articulator functions of the oropharynx.

We found no significant differences in acoustic parameters before versus after Han's uvulopalatopharyngoplasty, except for normalised noise energy. This was mainly because the acoustic parameters are greatly affected by the frequency, periodicity and amplitude of vocal fold vibration and glottal closure, and are less influenced by the vocal tract. This may explain why obstructive sleep apnoea hypopnoea syndrome patients have normally functioning activator organs. The observed changes in normalised noise energy may have been due to changes in upper airway resistance caused by anatomical abnormalities. Hyperplasia and relaxation of the oropharyngeal soft tissues may reduce the ability of obstructive sleep apnoea hypopnoea syndrome patients to control airflow; however, the reasons for this require further research.

Conclusion

These study findings indicate that the acoustic and articulatory characteristics of obstructive sleep apnoea hypopnoea syndrome patients differ from those of normal subjects. Han's uvulopalatopharyngoplasty is an effective procedure which has fewer post-operative complications than classical uvulopalatopharyngoplasty. Following Han's uvulopalatopharyngoplasty, obstructive factors in the oropharynx were relieved and the oropharyngeal cavity expanded, enabling patients' formant frequency to increase gradually to within the normal range, one month after surgery. Patients' vocal qualities improved, and their resonator and articulator functions were protected and enhanced.

References

1 Han D, Ye J, Lin Z, Wang J, Wang J, Zhang Y. Revised uvulopalatopharyngoplasty with uvula preservation and its clinical study. *ORL J Otorhinolaryngol Relat Spec* 2005;**67**:213–19
2 Delattre P. The physiological interpretation of sound spectrogram. *PMLA* 1951;**66**:864–75
3 Fujita S, Conway W, Zorick F, Roth T. Surgical correction of anatomic abnormalities in obstructive sleep apnea syndrome: uvulopalatopharyngoplasty. *Otolaryngol Head Neck Surg* 1981;**89**:923–34
4 Kezirian EJ, Weaver EM, Yueh B, Deyo RA, Khuri SF, Daley J *et al*. Incidence of serious complications after uvulopalatopharyngoplasty. *Laryngoscope* 2004;**114**:450–3
5 Friedman M, Ibrahim HZ, Vidyasagar R, Pomeranz J, Joseph NJ. Z-palatoplasty (ZPP): a technique for patients without tonsils. *Otolaryngol Head Neck Surg* 2004;**131**:89–100
6 Friedman M, Duggal P, Joseph NJ. Revision uvulopalatoplasty by Z-palatoplasty. *Otolaryngol Head Neck Surg* 2007;**136**:638–43
7 Coleman RF, Sly DE. Preoperative and postoperative voice analysis of uvulopalatopharyngoplasty patients. *Arch Otolaryngol Head Neck Surg* 1991;**117**:1345–9
8 Rihkanen H, Soini I. Changes in voice characteristics after uvulopalatopharyngoplasty. *Eur Arch Otorhinolaryngol* 1992;**249**:322–4
9 Nakai K, Sakakura A, Takahashi H, Sadaoka T, Kakitsuba N. Articulation after uvulopalatopharyngoplasty. *Eur Arch Otorhinolaryngol* 1996;**253**:417–20
10 Murry T, Bone RC. Acoustic characteristics of speech following uvulopalatopharyngoplasty. *Laryngoscope* 1989;**99**:1217–19

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