ACTA OTORHINOLARYNGOL ITAL 26, 110-114, 2006

ORIGINAL PAPER

Acoustic changes in voice after surgery for snoring: preliminary results

Risultati preliminari sull'analisi delle variazioni delle caratteristiche acustiche della voce dopo interventi di roncochirurgia

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Key words

Snoring • Surgical treatment • Voice • Acoustic analysis

Parole chiave

Russamento • Trattamento chirurgico • Voce • Analisi acustica

Summary

All surgical procedures for treatment of snoring and obstructive sleep apnoea modify the anatomical structure of the upper airways and the resonance characteristics of the vocal tract; this can lead to a modification in voice quality. Purpose of this study was to evaluate the possible modifications of the fundamental frequency (F0) and of the frequency and amplitude of the first (F1) and second (F2) formants of the 5 Italian vowels after different surgical procedures for snoring, to verify if and how these operations can influence voice quality. A total of 40 snoring or obstructive sleep apnoea syndrome patients, not affected by laryngeal, pulmonary or neurologic disorders likely to alter voice production, were selected for the study. All were submitted to acoustic voice analysis prior to surgery and again 1 month after discharge. F0 was unchanged. The frequency of F1 of the vowel /a/ audio of F2 of the vowel /e/ were significantly higher, while F1 of /i/ and F2 of /o/ and /u/ were significantly lower compared to pre-operative values. The modifications in the anatomical structure and volume of the vocal tract, induced by the surgical procedures used for the treatment of snoring, can modify the values of the formants and, as a consequence, quality of the voice. This change can be detected not only by means of the acoustic analysis but also by the patient itself. For this reason, singers and all professional voice users about to undergo surgical treatment for snoring should be informed of this potential modification of the voice not only for clinical reasons but also for legal purposes.

Riassunto

Tutte le procedure chirurgiche che vengono impiegate per il trattamento del paziente roncopatico alterano le strutture delle vie respiratorie superiori e possono quindi influenzare la qualità della voce poiché modificano le caratteristiche di risonanza del tratto vocale sopraglottico. Scopo del nostro lavoro è stato quello di valutare le eventuali modificazioni della frequenza fondamentale (F0) e dei valori di frequenza e di ampiezza della formante 1 (F1) e 2 (F2) delle cinque vocali dopo interventi di roncochirurgia, per verificare se e in che modo questi possano influenzare la qualità della voce. Quaranta pazienti russatori non affetti da patologie laringee, polmonari o neurologiche in grado di alterare la produzione vocale sono stati selezionati per lo studio. Tutti sono stati sottoposti ad analisi acustica della voce prima dell'intervento chirurgico ed un mese dopo la dimissione. La F0 è risultata sostanzialmente invariata. La frequenza della F1 della vocale /a/ e della vocale /e/ sono risultate significativamente più elevate, mentre la F1 della vocale /i/ e la F2 delle vocali /o/ e /u/ sono risultate significativamente più basse rispetto ai valori pre-operatori. Le modificazioni della morfologia e del volume del tratto vocale sopraglottico indotte dagli interventi di roncochirurgia possono modificare le formanti. Questo può comportare una modificazione della qualità della voce percepibile non solo mediante analisi acustica, ma anche potenzialmente mediante una valutazione soggettiva da parte del paziente stesso. Per tale motivo i cantanti e tutti coloro che utilizzano la voce a scopo professionale e che devono essere sottoposti ad interventi di roncochirurgia dovrebbero essere informati di tale eventualità ai fini non solo clinici, ma anche medico-legali.

Introduction

All surgical procedures for the treatment of snoring and obstructive sleep apnoea syndrome (OSAS) modify the anatomical structure of the upper airways and the resonance characteristics of the vocal tract; this can lead to a modification in the quality of the voice [1].

The size and shape of the acoustic spaces of the vocal tract (nasal, oral and pharyngeal cavities) and the coupling between those spaces determine areas of resonance, defined as "formants" [1 2]. Formant 1 (F1) is

usually associated with the height of the tongue and the degree of closure of the oropharyngeal cavity; formant 2 (F2) is associated with the degree of advancement of the tongue with respect to its neutral position; formant 3 (F3) is associated with the degree of rounding of the lips [1 2]. The frequencies and amplitudes of the formants define each vowel and significantly contribute to the overall quality of speech [1].

Several studies have already examined the potential changes in the acoustic characteristics of vocal quality after upper airway surgery, with conflicting results [2-13].

The purpose of the present study was to evaluate the possible modifications in fundamental frequency (F0) and of the frequency and amplitude of the first and second formants of the 5 Italian vowels after different surgical procedures for snoring, to establish if and how these operations can influence voice quality.

Material and methods

Subjects

All snoring or OSAS patients admitted to the Department of Otolaryngology of the University of Pavia, in the period between September 2003 and May 2005, and scheduled for upper airway surgery were evaluated for the study. A total of 40 patients (37 male, 3 female), aged between 23 and 65 years (mean 46, median 48), not affected by laryngeal, pulmonary or neurologic diseases, able to alter voice production, were selected for the study. All were submitted to acoustic voice analysis before surgery and again 1 month after discharge.

According to the clinical and polysomnographic data, patients were submitted to different surgical procedures, usually multilevel operations. The operations performed in each patient are shown in Table I. Moreover, in the event of tonsillectomy ± uvulopalatopharyngoplasty (UPPP), the amount of tissue removed was measured by dipping it into a fixed volume of saline solution and calculating the quantity (in ml) of water removed.

Acoustical voice analysis

Each subject was asked to pronounce a short speech and to produce each of the 5 Italian vowels /a/, /e/, /i/, /o/, /u/ three times, sustained for 5 seconds and at an intensity between 55 and 65 dB. The acoustic signal was acquired with a microphone (Sennheiser e945), at a distance of 20 cm and 45° from the patient's mouth, connected to a computer and digitally recorded using Atmos Lingwave software (version 1.0.0.1) at a 50 KHz sampling rate and 16 bit resolution.

The F0 of speech was calculated on the spectrogram 0-4000 Hz of the short speech. Linear predictive analysis (LPC) was used to analyse the frequency and amplitude (A) of F1 and F2 of each vowel. The principle of this mathematical transformation is to separate the speech signal by filtration from partial tones and, as a result, an indirect estimation of the anatomical relations of the vocal tract can be obtained [11].

Statistical analysis

Pre- and post-operative values of F0, F1, F2, A1, A2 and of their absolute and percentual differences were analysed. Data were expressed as mean (M) and standard deviation (SD). Since many variables were not normally distributed (Shapiro-Wilk's test), comparisons pre-post were performed using Student t test for paired data or the non parametric Wilcoxon Matched pairs test, as appropriate. Correlations between the differences in the frequency and amplitude values of the formants and the amount of tissue removed were analysed with the Poisson "r" coefficient. $p < 0.05$ was considered statistically significant. All tests were two-sided. No adjustment for multiple comparisons was made, as this study was intended as explorative rather than confirmatory. Analyses were performed with "Statistica for Windows" software (StatSoft, Inc. 2004, Tulsa, OK, USA).

Results

Mean (M) and standard deviation (SD) of the pre- and post-operative values of F0, as well as the M and SD of their differences and statistical significance are outlined in Table II. The mean values of F0, evaluated 1 month post-operatively, did not change significantly.

M and SD of the frequency and amplitude values of the formants, before and after surgery, as well as the M and SD of the differences between the values and statistical significance are outlined in Table III.

The frequency values of F1 and F2 of the vowel /a/ measured 1 month post-operatively increased; the difference in the F1 values, in particular, being statistically significant.

The frequency value of F1 of the vowel /e/ decreased, but the difference was not statistically significant; while the frequency value of F2 increased significantly.

F1 of the vowel /i/ was significantly lower compared to the pre-operative value, while F2 was higher, even if this difference was not statistically significant.

The post-operative frequency values of F1 and F2 of the vowels /o/ and /u/ decreased; the differences being statistically significant particularly for F2 of both vowels.

No statistically significant variations were observed for the amplitude values of the formants considered.

Table I. Surgical procedures performed and amount of resected pharyngeal tissue.

Patients	Septoplasty	Turbinoplasty	LAUP	UPPP	Tonsillectomy	Hyoid suspension	Tongue base RF	Resected tissue (ml)
CF				X				4
MM				X				4
GA				X	X			15
FC				X	X			12
SM				X	X			17
GG				X	X			12
MA				X	X			10
AS	X	X						0
LV	X						X	0
BM		X			X			8
LR		X		X	X			10
CM		X		X	X			14
SL		X		X	X			12
BM				X	X	X		12
CS				X	X	X		12
AO	X			X	X			12
CG	X	X		X				6
DDG	X	X		X				6
VF	X	X		X				3
SD	X	X			X			8
PP	X			X		X		2
RG		X		X	X	X		9
ME	X			X	X	X		13
COA	X	X		X	X			12
SC	X	X		X	X			9
CR	X	X		X	X			12
DLD	X	X		X	X			12
RM	X	X		X	X			12
TA	X	X		X	X			10
BA	X	X		X	X			14
IA	X	X		X	X			16
CA	X	X	X			X		6
MG		X		X	X	X		13
GC		X		X	X	X		12
VC	X	X		X	X	X		10
PL	X	X		X	X	X		12
TG	X	X		X	X	X		11.5
LFA	X	X		X	X	X		12
FA	X	X		X	X	X		12
LF	X	X		X	X	X		14

LAUP = laser assisted uvulopalatoplasty; UPPP = uvulopalatopharyngoplasty; RF = radiofrequency

As far as concerns the correlation analysis between the amount of resected pharyngeal tissue and the variations in frequency of the formants of each vowel, the "r" coefficient did not exceed 0.25.

Discussion

The fundamental frequency and the formants are influenced by the different muscular and aerodynamic characteristics of the vocal tract. The fundamental question is, whether the modification of the volume and the resonance of the supraglottic vocal tract can determine a significant variation in the quality of the vocal sound. Over the last 15 years, several reports have been published on this topic. Lin et al. [3] examined the formants of the five vowels in 15 patients submitted to tonsillectomy. The fourth formant increased in all cases. Other authors [6 8] observed a decrease of the third formant, after tonsillectomy. In both studies, F0, F1 and F2 were unchanged. Other authors [4 5] presented the same results in patients submitted to UPPP with or without tonsillectomy. Brosch et al. [11], on the contrary, in 12 UPPP patients,

Table II. Mean (M) and standard deviation (SD) of pre- and post-operative values of fundamental frequency (F0) and of differences (Δ), measured in Hertz.

	Pre-operative F0 (M ± SD)	Post-operative F0 (M ± SD)	Δ F0 (M ± SD)	Statistical significance (p < 0.05)
Hz	120.1 ± 29.5	120.63 ± 27.02	0.52 ± 11.92	0.83

Table III. Mean (M) and standard deviation (SD) of pre- and post-operative frequency (Hz) and amplitude (dB) values of different formants considered and of their differences (Δ).

		Pre-operative (M ± SD)	Post-operative (M ± SD)	Δ (M ± SD)	Statistical significance (p < 0.05)
/a/	F1 (Hz)	722.12 ± 92.77	759.93 ± 87.61	37.25 ± 74.07	0.003
	F2 (Hz)	1210.07 ± 115.65	1215.26 ± 100.33	15.20 ± 79.92	0.67
	A1 (dB)	29.11 ± 5.29	29.29 ± 5.92	0.18 ± 5.76	0.84
	A2 (dB)	23.31 ± 6.07	24.33 ± 5.54	0.42 ± 6.43	0.67
/e/	F1 (Hz)	394.33 ± 78.93	376.63 ± 73.36	-17.69 ± 58.85	0.06
	F2 (Hz)	2045.53 ± 223.72	2097.49 ± 219.28	51.96 ± 177.72	0.04
	A1 (dB)	31.91 ± 4.06	32.40 ± 3.15	0.49 ± 4.64	0.51
	A2 (dB)	17.85 ± 5.66	16.44 ± 4.97	-1.41 ± 5.47	0.11
/i/	F1 (Hz)	266.42 ± 54.61	247.99 ± 43.53	-18.42 ± 45.33	0.02
	F2 (Hz)	2262.66 ± 194.23	2287.29 ± 209.63	24.64 ± 144.00	0.28
	A1 (dB)	33.21 ± 4.27	33.32 ± 3.33	0.11 ± 4.96	0.89
	A2 (dB)	15.79 ± 5.45	14.54 ± 6.21	-1.25 ± 6.22	0.21
/o/	F1 (Hz)	533.90 ± 79.71	519.67 ± 87.80	-14.22 ± 75.64	0.24
	F2 (Hz)	898.82 ± 123.07	859.12 ± 99.52	-39.70 ± 106.52	0.02
	A1 (dB)	35.34 ± 5.30	33.42 ± 4.63	-1.91 ± 6.13	0.05
	A2 (dB)	28.70 ± 5.53	28.70 ± 5.53	0.93 ± 7.49	0.44
/u/	F1 (Hz)	330.27 ± 79.89	316.99 ± 57.44	-13.27 ± 70.89	0.12
	F2 (Hz)	681.67 ± 127.36	654.39 ± 111.00	-27.28 ± 108.26	0.04
	A1 (dB)	37.42 ± 6.04	37.98 ± 4.40	0.56 ± 5.72	0.53
	A2 (dB)	25.54 ± 6.21	26.01 ± 6.49	0.48 ± 6.97	0.66

F1 = first formant; F2 = second formant; A1 = amplitude first formant; A2 = amplitude second formant

observed an increase of F0 and a significant decrease of F2 of the vowels /o/ and /u/; while Nakai et al. [7] constantly showed, in 12 UPPP patients, an increase of F1 and F2 of the vowel /e/ and a decrease in F1 and F2 values of the vowel /u/.

The post-operative acoustic analysis, in our patients, did not reveal significant modifications in the F0 values. This could be explained by the fact that the adduction of the vocal cords and the vibratory mucosal wave, which generate the F0, are not influenced by the surgical procedures used in the treatment of snoring problems.

Analysis of the formants, on the other hand, demonstrated a significant increase in the F1 value of the vowel /a/ and in F2 of the vowel /e/, a significant decrease in the F1 value of the vowel /i/ and in F2 of the vowels /o/ and /u/. The decrease in the values of these formants could depend on the increased volume of the oropharyngeal cavity caused by the anterior-posterior advancement of the tongue induced by the hyoid suspension and on the increasing of the palatal arch determined by the UPPP and/or the tonsillectomy. The increased oropharyngeal cavity, however, should lower all the formants, but this is not always the case. The absence of modifications or, even, the increase of the formant frequencies encountered in the literature, and confirmed by our study, could depend upon the compensatory mechanisms of contrac-

tion of the pharyngeal musculature and of tongue position induced by the new configuration of the oropharynx following the surgical treatment [4].
Moreover, Brosh et al. [11] demonstrated a statistically significant correlation between the amount of resected pharyngeal tissue during UPPP and the variation in the frequency value of the formants. This phenomenon has not been confirmed by our study. In fact, we found no correlation between the amount of tissue removed, during the different surgical procedures, and the modification of the formants frequency.
Probably, it is not the amount of resected tissue that determines the modification of the formants-frequency but rather the new size and shape of the vocal tract resulting from the operation, even if long-term results are needed to evaluate this possibility.
Theoretically, it might be useful to establish the effects of each type of surgical procedure on the acoustic spectrogram of the patients, to evaluate which operation exerts the major effects on the formants. In reality, instead, snoring and OSAS patients are often submitted to multilevel surgical procedures, and, therefore, this kind of evaluation becomes difficult.

Conclusions

The modifications in the size and shape of the vocal tract, resulting from surgical treatment for snoring, can modify the formants. This can lead to a change in voice quality that can be perceived not only by the acoustic analysis, but also by the patient him/herself. For this reason, singers and all professional voice users undergoing surgery for snoring, should be informed of this potential voice modification, not only for clinical reasons, but also for legal purposes.

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■ Received: August 8, 2005
Accepted: September 23, 2005

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