Original Article
Spectrum analysis of Chinese vowels formant in patients with tongue carcinoma underwent hemiglossectomy

Yujie Liang, Fahmi Ahmed Numan, Kan Li, Guiqing Liao

Department of Oral and Maxillofacial Surgery, Guanghua School of Stomatology, Guangdong Provincial Key Laboratory of Stomatology, Sun Yat-sen University, Guangzhou, China

Abstract: Objectives: Tongue is the most important phonatory organ in stomatognathic system. Radical resection of tongue squamous cell carcinoma can cause tongue defect and result in serious oral dysfunction, especially in phonetic function. This study aims to reveal the influence of tongue cancer, tongue defect and tongue reconstructions to phonetic function of tongue cancer patients. Study design: Formant spectrum analysis of Chinese vowels was performed by linear predictive coding (LPC) in tongue squamous cell carcinoma patients (before surgery and 3 months, 9 months and 2 years after surgery) and normal people. Patients with tongue squamous cell carcinoma were divided into reconstruction group and non-reconstruction group. In reconstruction group, patients underwent tongue reconstruction with radial forearm free flap (RFFF) and lateral arm free flap (LAFF), respectively. Results: 45 patients and 40 normal people were included. Differences were statistically significant between patients and normal persons, between patients before surgery and after surgery, between non-reconstruction group and construction group 2 years after operation. No statistical significance was found between patients underwent tongue reconstruction with RFFF or LAFF 2 years after operation. Conclusions: This study showed that tongue cancer and tongue defect after radical resections affected phonetic function of patients. Tongue reconstruction with free flaps could restore phonetic function to some extent. The efficiency of tongue reconstruction with RFFF and LAFF respectively were similar.

Keywords: Tongue squamous cell carcinoma, tongue reconstruction, formant spectrum analysis, Chinese vowels, linear predictive coding

Introduction

Tongue is the most important phonatory organ in stomatognathic system. In pronunciation, tongue can not only change its own morphology and position, adjust shape of sympathetic chord cavity, but also complete main phases of pronunciation together with neighboring tissues, such as teeth, alveolar bones, soft palate and hard palate [1]. Tongue defect results in a serious impact on pronunciation.

Tongue squamous cell carcinoma is one of the most common malignant tumors in oral and maxillofacial region [2]. Radical resection of tongue carcinoma causes damage to tongue shape and even results in a serious oral cavity dysfunction of voice and swallow. This would pose a double attack to patient physically and mentally, moreover, seriously affect living quality of patients.

Voice is one of the basic communication ways in human beings. Changes in normal physiologic condition of various phonatory organs within oral cavity of patients with tongue carcinoma cause serious influence on voice. They are mainly manifested in the following aspects: (i) Length and width of tongue body shorten significantly, flexibility of tongue body decreases markedly and space within oral cavity changes; (ii) When tissue flaps are used in tongue reconstruction, the movement of flaps are only dependent on remaining tissues of tongue body, thus speech intelligibility is significantly affected; (iii) The damage of neighbor struc-

Table 1. Comparison of age and gender of patients and normal people

	Age (years)		x^2	P	Gender		x^2	P
	< 45	≥ 45			Male	Female		
Patients (45)	18	27	0.000	1	26	19	0.066	0.797
Normal people (40)	16	24			22	18		
Reconstruction (25)	14	11	0.538	0.462	15	10	0.000	1
Non-reconstruction (20)	9	11			12	8		
RFFF (15)	9	6	0.000	1	9	6	0.000	1
LAFF (10)	6	4			6	4		

tures and formation of oral scar both severely affect functions of corresponding phonatory organs, and subsequently affect speech intelligibility; (iv) Salivation caused by structure damage and operative stimulation after operation influences pronunciation. With constant induction of functional surgery concept, various remediation technologies of tissue flaps are widely applied to clinic and become mature. What remediation measures to take after tongue resection is more beneficial to functional recovery of voice after operation is still controversial [3-5].

To apply mathematical measure to deal with speech function, Fant et al. have proposed speech production model and physical model. He considered that speech production can be divided into three parts: sound source, sound channel transmission and oronasal radiation [6]. To measure speech function, the three parts are supposed to be linearly separable. In voice signal processing, continuous sound wave should be firstly performed by analog-to-digital conversion (A/D). Sound wave can be input to computer after being transformed to digital signal. Such digital signal must be transformed to analog signal, then can be heard and judged for humans. The process is called 'digital analog (D/A) conversion'. LPC (Linear Predictive Coding), which can calculate fundamental frequency of sound wave, resonance peak, correlation coefficient and carry out spectrum analysis, is the most essential measure in voice signal processing.

Phonemes are classified into voiced consonant, voiceless consonants and vowel. Formant [7, 8] is resonance frequency of acoustic cavity when pronouncing vowel. It is formed by all sympathetic chord cavities between vocal cord and oral lips (size is decided by the positions of soft palate, tongue, teeth and lips), represent-

ing resonance characteristics of sound channel. Many scholars have considered that the first three formants have qualitative prescription of vowel color. Due to the differences of width, thickness and length, and vibration frequency, normal and pathological pronunciation of different and same sounds have different resonance frequencies of acoustic cavity, which is called Formant Patten (F-Patten). Different vowels have different F-Patten, which is determined by shapes of different sound channels [9].

Our study aims to evaluate characteristics of vowel articulation in patients with tongue carcinoma before and after operation, and create conditions for clinician to perform well-directed voice rehabilitation training.

Materials and methods

Cases data

From January 2003 to March 2009, for 45 tongue squamous cell carcinoma patients (each primary focus is T2, aged from 25-67 yrs) with tongue carcinoma treated in Department of Oral and Maxillofacial Surgery, Hospital of Stomatology, Sun Yat-Sen University, formant spectrum analysis of Chinese vowels was performed by LPC (before surgery and 3 months, 9 months and 2 years after surgery). Additionally, 40 normal people (aged from 26-63 yrs) were selected as control to undergo formant spectrum analysis of Chinese vowels. The inclusion criteria were as follows: (i) no obvious intellectual and hearing disorder; (ii) no obvious provincial accent, voice sample can be successfully collected; (iii) no symptoms, such as cold and nasal obstruction when recording. Written informed consents were obtained from each patient. The study protocols were approved by the Ethical Committee of Hospital of Stomatology, Sun Yat-Sen University.

Table 2. Comparison of vowel formant means of patients with tongue carcinoma (before surgery) and normal people (Hz, x ± s)

Vowel	Group	F1	F2	F3
/a/	Tongue carcinoma Patient	843.9 ± 159.0	1298.8 ± 251.3	2708.4 ± 153.9*
	Normal person	865.3 ± 166.4	1213.8 ± 140.5	2912.8 ± 99.5
/o/	Tongue carcinoma Patient	475.3 ± 100.7	809.6 ± 209.5	2728.0 ± 201.2**
	Normal person	502.3 ± 87.0	871.4 ± 40.7	3010.0 ± 199.5
/e/	Tongue carcinoma Patient	476.0 ± 31.2	1245.4 ± 81.9**	2730.8 ± 91.5
	Normal person	526.7 ± 92.2	1072.6 ± 57.7	2884.4 ± 224.3
/i/	Tongue carcinoma Patient	377.6 ± 58.1*	2424.7 ± 282.8	3178.9 ± 224.2
	Normal person	282.7 ± 50.9	2570.2 ± 249.8	3115.4 ± 275.9
/u/	Tongue carcinoma Patient	243.9 ± 55.2*	809.6 ± 162.9	2694.1 ± 407.8
	Normal person	371.3 ± 42.4	718.0 ± 99.6	2714.7 ± 439.2
/ü/	Tongue carcinoma Patient	255.1 ± 20.8	2157.4 ± 386.9	2667.3 ± 428.9*
	Normal person	307.1 ± 56.2	1914.7 ± 133.1	2357.3 ± 160.3

*: $P < 0.05$, **: $P < 0.01$.

Patients with tongue cancer were divided into two groups, reconstruction group (25 patients, aged from 25-63 yrs) and non-reconstruction group (20 patients, aged from 32-67 yrs). In reconstruction group, patients underwent tongue reconstruction with radial forearm free flap (RFFF, 15 patients) and lateral arm free flap (LAFF, 10 patients), respectively.

Voice recording and analysis

Voice signal input: Select 6 pure vowels of Chinese pinyin /a/o/e/i/u/ü/ as test samples. In specialized soundproof room, subjects in a natural and relaxed state sit up when pronouncing. Mouth is 10 cm away from mike, intensity of phonation is a little greater than that in ordinary talk. Sound holding-time of each single word is about 1.5 s, and interval is 1 s. Using Cooledit Software, press Position 16 and single sound channel, sample at sampling frequency of 16000 Hz, and file format is Wav.

Voice spectrum analysis: In Praat workstation, record mean value and standard deviation of 1st, 2nd and 3rd formants (F1, F2, F3) of tested vowels with linear predictive coding (LPC). This experiment flow can be expressed as follows: Tested voice pronounced by speaker → mike → polygraph → sample preservation → phonetic analysis system → voice pictorialization → test and quantification → completion of analysis and evaluation.

Statistical analysis

All statistical analysis was performed with SPSS 13.0 by Independent Samples T-test and Paired-Sample T-Test. Differences at $P < 0.05$ were considered significant.

Results

Wound healing condition after operations

The operations were finished smoothly. In reconstruction group, flaps all survived, no vascular crisis occurred, and incisions healed by first intention. In post-operation follow-up, no local relapse or metastasis occurred; reconstructed tongue had satisfactory shape and mobility with certain toughness and elasticity.

Demographic information

Table 1 summarized the age and gender information of the patients and normal people. No statistical difference was noticed in the age and gender.

Result of phonetic analysis

Among pure vowels of patients with tongue carcinoma before surgery, values /a/F3, /o/F3 and /u/F1 were lower as compared to normal people, and values /e/F2, /i/F1 and /ü/F3 were higher. Differences were statistically significant (**Table 2**).

It could also be seen that among pure vowels of patients with tongue carcinoma 3 months after operation, values /o/F2, /e/F1, /i/F1, /u/F1 and /u/F2 were higher as compared to those before operation, and values /a/F3, /i/F3, /ü/F2 and /ü/F3 were lower. Differences were statistically significant (**Table 3**).

Table 3. Comparison of vowel formants of patients with tongue carcinoma in reconstruction group before and after operation (Hz, x ± s)

Vowel	Group	F1	F2	F3
/a/	Pre-operation	839.5 ± 121.6	1521.3 ± 165.3	2933.3 ± 277.3
	Post-operation	857.1 ± 203.6	1497.4 ± 224.2	2862.9 ± 335.9*
/o/	Pre-operation	597.2 ± 72.7	799.5 ± 85.2	2413 ± 113.2
	Post-operation	560.8 ± 154.9	923.6 ± 133.6**	2567.0 ± 210.5
/e/	Pre-operation	398.0 ± 96.3	1445.4 ± 104.0	2613.5 ± 114.7
	Post-operation	478.3 ± 108.3*	1598.4 ± 229.2	2676.0 ± 194.6
/i/	Pre-operation	211.2 ± 44.5	2356.1 ± 311.9	3255.0 ± 224.8
	Post-operation	312.0 ± 51.9**	2200.6 ± 443.1	3184.1 ± 126.3*
/u/	Pre-operation	242.3 ± 99.7	765.0 ± 338.2	2812.3 ± 345.3
	Post-operation	371.7 ± 84.2*	965.2 ± 302.1*	2697.4 ± 330.4
/ü/	Pre-operation	251.0 ± 33.3	2277.5 ± 342.4	2857.0 ± 322.7
	Post-operation	293.6 ± 56.6	1995.0 ± 300.3*	2691.4 ± 313.8**

*: $P < 0.05$, **: $P < 0.01$.

Table 4. Comparison of vowel formant means of patients with tongue carcinoma in reconstruction group 3 months and 9 months after operation (Hz, x ± s)

Vowel	Group	F1	F2	F3
/a/	After 3 months	857.1 ± 203.6	1497.4 ± 224.2	2862.9 ± 335.9
	After 9 months	863.2 ± 161.1	1399.7 ± 137.6	2680.8 ± 335.2
/o/	After 3 months	560.8 ± 154.9	923.6 ± 63.8	2567.0 ± 210.5
	After 9 months	566.9 ± 107.3	1399.7 ± 137.6	2849.6 ± 382.6
/e/	After 3 months	478.3 ± 108.3	1598.4 ± 229.2	2676.0 ± 194.6
	After 9 months	536.3 ± 82.3	1426.8 ± 190.2	2770.2 ± 309.0
/i/	After 3 months	312.0 ± 51.9	2200.6 ± 443.1	3184.1 ± 126.3
	After 9 months	316.1 ± 65.9	2225.9 ± 223.9	2991.9 ± 465.1
/u/	After 3 months	371.7 ± 84.2	965.2 ± 302.1	2697.4 ± 330.4
	After 9 months	364.2 ± 72.2	860.7 ± 105.6	2770.9 ± 155.6
/ü/	After 3 months	293.6 ± 56.6	1995.0 ± 300.3	2691.4 ± 313.8
	After 9 months	301.8 ± 56.2	1936.8 ± 156.8	2594.9 ± 285.7

In **Table 4**, analytical results of vowel formant of patients with tongue carcinoma 3 and 9 months after radical resection and tongue reconstruction showed no statistical significance.

When comparing vowel formant of patients with or without tongue construction 2 years after operation, it could be seen that values /a/, /o/, /e/, /i/ F1, /ü/ F2 and /u/ F3 in non-reconstruction group were higher than those in reconstruction group, while /ü/ F3 was lower. Differences were statistically significant (**Table 5**).

Then we compared vowel formants of patients underwent tongue reconstruction with RFFF or LAFF 2 years after operation. Analytical results showed no statistical significance (**Table 6**).

Discussion

In this study, we applied spectrum analysis of Chinese vowels formant to reveal the influence of tongue cancer, tongue defect and tongue reconstructions to phonetic function of tongue cancer patients. These data can provide some knowledge to oral functions and some suggestion for clinical practice.

Pronunciation is the process that vibration of the vocal cords generates sound waves, and then organs, such as larynx, tongue, palate, lip and mandible modulate them. Voice finally

Table 5. Comparison of vowel formants of tongue carcinoma patients in reconstruction group and those in non- reconstruction group 2 years after operation (Hz, x ± s)

Vowel	Group	F1	F2	F3
/a/	Non-reconstruction Group	1011.2 ± 87.6*	1528.7 ± 202.1	2881.9 ± 129.0
	Reconstruction Group	859.5 ± 112.0	1322.3 ± 144.5	2899.7 ± 188.4
/o/	Non-reconstruction Group	738.4 ± 81.4**	958.1 ± 172.7	3076.1 ± 103.2**
	Reconstruction Group	534.2 ± 111.4	876.5 ± 99.6	2877.1 ± 205.7
/e/	Non-reconstruction Group	669.6 ± 92.9**	1433.0 ± 166.7**	2925.1 ± 108.6
	Reconstruction Group	532.2 ± 88.6	1132.6 ± 87.4	2847.9 ± 133.2
/i/	Non-reconstruction Group	431.6 ± 86.4**	2294.4 ± 171.9	3360.9 ± 139.9
	Reconstruction Group	311.1 ± 77.6	2477.4 ± 210.6	3132.9 ± 177.8
/u/	Non-reconstruction Group	362.2 ± 84.2	773.8 ± 148.1	3151.6 ± 124.5*
	Reconstruction Group	367.8 ± 66.5	728.6 ± 111.8	2733.6 ± 151.7
/ü/	Non-reconstruction Group	329.7 ± 86.4	2183.1 ± 149.7**	2145.0 ± 211.5*
	Reconstruction Group	303.0 ± 66.7	1931.2 ± 132.7	2377.8 ± 243.4

*: $P < 0.05$, **: $P < 0.01$.

Table 6. Comparison of vowel formants of radial forearm free flap and lateral arm free flap (Hz, x ± s)

Vowel	Group	F1	F2	F3
/a/	RFFF	858.9 ± 98.7	1199.5 ± 242.3	2809.0 ± 78.7
	LAFF	849.9 ± 92.1	1205.1 ± 233.1	2797.3 ± 102.2
/o/	RFFF	513.4 ± 112.0	967.1 ± 197.3	2987.0 ± 311.3
	LAFF	499.0 ± 122.3	942.1 ± 210.0	2899.4 ± 276.2
/e/	RFFF	481.7 ± 111.2	1199.2 ± 99.6	2901.9 ± 322.1
	LAFF	412.1 ± 132.1	1212.1 ± 122.1	2843.5 ± 214.5
/i/	RFFF	301.1 ± 88.4	2230.9 ± 123.5	3211.2 ± 122.4
	LAFFF	299.5 ± 122.3	2178.0 ± 144.3	2978.6 ± 155.9
/u/	RFFF	355.9 ± 112.0	1001.8 ± 77.9	2677.9 ± 322.1
	LAFFF	371.3 ± 42.4	977.8 ± 76.8	2587.9 ± 299.0
/ü/	RFFF	311.7 ± 77.8	2213.8 ± 220.9	2357.3 ± 188.0
	LAFF	299.0 ± 48.8	2311.0 ± 213.0	2401.9 ± 155.9

reported that the first formant F1 was closely related to high low position of tongue. Higher was tongue position, lower was F1. The second formant F2 was related to anteroposterior position of tongue. More posterior was tongue position, lower was F2. The third formant F3 was related to soft palate lowering and velopharyngeal closure. Lower was soft palate, lower was F3 [12-14]. Conclusion of Chinese continuous pronunciation studied by Wu et al. [7] has also revealed that F1 was related to high low position of tongue, namely mandible opening, and F2 was related to anteroposterior position of tongue.

made lies on spectral property of sound source and transmission characteristics of sound channel as well. Sound is formed by synergistic effect of dynamical system, vibration system and resonance system. Tongue is important movable organ, participating in formation of resonance system. Shape and position in oral cavity of tongue are main factors to determinate vowel formant [10].

Mode of vowel formant represents resonance characteristics of sound channel. Different formant modes represent different vowel characteristics; the first three formants F1, F2 and F3 have qualitative prescription of vowel color. Analysis of the first three formants can reveal partial characteristics of pure vowel [11]. It was

Linguistic function of tongue is mainly dependent on its length and flexibility. The results of this research suggested that voice changed significantly in tongue cancer patients when compared to normal persons. Tongue carcinoma affects normal phonetic function.

After operation of tongue carcinoma, length and flexibility of tongue body decreased, and space within oral cavity changes. Speech intelligibility of patients declines significantly. We collected voice samples 3 months after operation, for wound swelling of patients wears off generally to guarantee comparison conducted under the same condition. From **Table 3**, it could be seen that, even with tongue reconstruction, among pure vowels of patients with

tongue carcinoma after operation, values /o/ F2, /e/F1, /i/F1, /u/F1 and /u/F2 increased, and values /a/F3, /i/F3, /ü/F2 and /ü/F3 decreased. After operation, when vowels /e/, /i/, /u/ were pronounced, the first formant F1 increased. It may be because at hemi-glossectomy mouth floor was usually linked, suture of wound edge and remaining mucosa of mouth floor affected uplift of tongue body, which was required when vowels were pronounced. Therefore, increase of F1 may be related to lowering of tongue position. Theoretically, /o/ and /u/ are back vowels, and tongue body post-condensates at pronunciation. When /o/ and /u/ were pronounced, the second formant F2 increased. It was because that movement disorders of tongue body lead to difficulty in post-condensation; the more anterior was tongue position, the higher was F2. However, /ü/ is a front vowel. At pronunciation, tongue body protracts, thus F2 decreases. When /a/, /i/ and /ü/ were pronounced, the third formant F3 decreased, indicating that velopharyngeal closure was not completed. We considered that tongue body shortened after tongue carcinoma operation and that mouth floor was usually linked by tongue carcinoma operation might be possible reasons. After suture, traction caused no contact of tongue back and soft palate tip, and formed a big aperture. Therefore, the third formant F3 decreased when /a/, /i/ and /ü/ were pronounced.

This study showed that vowel formants of patients with tongue carcinoma in reconstruction and non-reconstruction groups were significantly different. It demonstrated that application of various flaps to repair tongue defect could restore phonetic function to some extent.

Then we compared phonetic function after tongue construction with radial forearm free flap and lateral arm free flap respectively. Analytical results of vowel formants showed no significant difference between two groups 2 years after tongue reconstruction. In our previous studies, we investigated the clinical efficiency of tongue reconstruction with RFFF and LAFF, respectively, and short-term outcomes were satisfactory in the postoperative appearance, speech and swallowing functions [15, 16]. Recently we showed that no statistical difference was identified in the long-term quality-of-life (5-9 years follow-up) of patients underwent tongue reconstruction with RFFF or LAFF

(data not showed). All these data indicated that in cases of moderate tongue defects, the efficiency of reconstruction with RFFF and LAFF were similar.

In some parts of this study, although certain significant differences were revealed, we were not able to conclude unique change patterns of vowel formants. It may due to that samples size was limited to get obvious patterns.

In conclusion, by spectrum analysis of Chinese vowels formant in tongue cancer patients, this study showed that tongue cancer and tongue defect after radical resections affected phonetic function of patients; tongue reconstruction with free flaps (RFFF and LAFF) could restore phonetic function to some extent, and the efficiency of tongue reconstruction with RFFF and LAFF respectively were similar.

Disclosure of conflict of interest

None.

Address correspondence to: Dr. Guiqing Liao, Department of Oral and Maxillofacial Surgery, Guanghua School of Stomatology, Guangdong Provincial Key Laboratory of Stomatology, Sun Yat-sen University, 56 West Lingyuan Road, Guangzhou 510055, China. Tel: +86-20-83862531; Fax: +86-20-83822807; E-mail: drliaoguiqing@126.com

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