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ORIGINAL ARTICLE

Increased nasality of connected speech in patients underwent modified Lothrop procedure for refractory chronic rhinosinusitis: Cross-sectional and prospective study

Yi-An Pan[a], Ying-Piao Wang[a,b,c], Guo-She Lee[d,e], Li-Chun Hsieh[a,b,c,*], Yi-Chen Chen[f]

[a]Department of Otolaryngology Head and Neck Surgery, Mackay Memorial Hospital, Taipei, Taiwan, ROC; [b]School of Medicine, Mackay Medical College, New Taipei City, Taiwan, ROC; [c]Department of Audiology and Speech Language Pathology, Mackay Medical College, New Taipei City, Taiwan, ROC; [d]School of Medicine, College of Medicine, Yangming Campus, National Yang Ming Chiao Tung University, Taipei, Taiwan, ROC; [e]Department of Otolaryngology, Taipei City Hospital, Ren-Ai Branch, Taipei, Taiwan, ROC; [f]Department of Special Science, University of Taipei, Taipei, Taiwan, ROC

Abstract

Background: The endoscopic modified Lothrop procedure (EMLP) is performed to create a large frontal neostium in patients who had failed previous frontal sinus surgeries. EMLP causes obvious changes in the volume and anatomy of the sinuses, which may cause a more significant change in nasality. This study aimed to evaluate the changes in nasalance in patients who underwent EMLP by comparing their preoperative nasalance to the established normative values and postoperative nasalance.

Methods: This was a prospective study. Twenty-one patients diagnosed with refractory frontal sinusitis who were indicated to undergo EMLP were enrolled. One hundred one healthy participants were enrolled as norm references. The Nasometer II Model 6400 (KayPENTAX) was used to analyze the nasalance scores. Nasalance scores were tested before surgery and 1 and 3 months after the surgery.

Results: The normative references of nasalance were (mean ± SD) 14.6% ± 6.7%, 39.4% ± 8.4%, and 55.8% ± 8.3% for the oral passage, oral-nasal passage, and nasal sentences, respectively. The mean nasalance scores pre-EMLP and 1 and 3 months post-EMLP were 23.2% ± 9.6%, 29.0% ± 9.3%, and 29.9% ± 0.4% for the oral passage; 48.7% ± 10.7%, 54.7% ± 7.7%, and 56.4% ± 7.2% for the oral-nasal passage; and 62.7% ± 10.9%, 69.8% ± 6.7%, and 70.7% ± 6.4% for the nasal sentences, respectively. Compared with the normative references, pre-EMLP nasalance was higher for all the three speech stimuli (t-test, $p < 0.05$). Post-EMLP nasalance also significantly increased for all the three stimuli at the 1- and 3-month follow-up visits (Paired t-test, $p < 0.05$).

Conclusion: EMLP has a short-term impact on resonance; however, long-term follow-up is required for further study.

Keywords: Connected speech; Modified Lothrop procedure; Nasality; Nasometer; Resonance

1. INTRODUCTION

Voice characteristics depend on the sound produced by the vocal cords and the sound resonance from the vocal tract. Any change in the structure or configuration of these areas can result in resonance disorders.[1] Voice resonance in the oral and nasal cavities are an important factor that determines voice quality. Abnormalities in voice amplification in the oral and nasal cavities are classified as hypernasality, hyponasality, and mixed resonance based on the degree of nasalization during sound production. These resonance disorders can lead to deterioration in voice quality, voice volume, and speech intelligibility.

Nasometers are currently the most widely used computer-based devices for analyzing the nasalance of different languages and patients with resonance disorders. They display the nasalance scores in real-time and calculate the average data for the entire sentence or passage at the end of testing.

Ha and Cho[2] and Kummer et al[3] reported greater consistency in nasalance performance when using connected-speech stimuli. Kummer[4] indicated that oral, oral-nasal, and nasal passages play roles in diagnosing different etiologies of resonance disorders. Oral passage is used to examine hypernasality and velopharyngeal insufficiency, and nasal passage is used to evaluate hyponasality. The combination of oral, oral-nasal, and nasal passages is needed to examine the timing of velopharynx opening and closing.

Standard passage speech stimuli and normative references of nasalance scores have been well established in several languages. Although some Mandarin studies have investigated nasalance using vowels, syllables, and sentences,[5,6] there are no published normative references for the nasalance of oral passages, oral-nasal passages, and nasal sentences. Thus, this study first aimed to establish standard passage speech stimuli in Mandarin and

* *Address Correspondence. Dr. Li-Chun Hsieh, Department of Otolaryngology-Head and Neck Surgery, Mackay Memorial Hospital, 92, Section 2, Chung-Shan North Road, Taipei 104, Taiwan, ROC. E-mail address: lichunhsieh1978@gmail.com (L.-C. Hsieh)*

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define normative references for nasalance scores for cross-sectional analyses.

Previous studies have reported that sinonasal surgery can affect nasality.[5,7] Even minor alterations in the nasal cavities and paranasal sinuses can affect the resonance of the nasal passage and cause significant changes in the nasality and voice spectrum.[8,9] In our previous study, patients with severe bilateral chronic rhinosinusitis with nasal polyposis had significantly lower nasalance scores, which were negatively correlated with endoscopic polyp grading scores.[10] However, Watterson[11] explored the effect of nasal decongestion and found that there was only a weak correlation between nasalance scores and nasal patency, which was measured with rhinometry. Jiang[5] also concluded that the nasalance scores increased after endoscopic sinus; however, the nasalance scores did not correlate with the increase in nasal volume. Therefore, whether the changes in anatomic structures and sinus volume affect resonance warrant further exploration.

The endoscopic modified Lothrop procedure (EMLP) is an extended frontal sinus surgery and a well-developed salvage surgery for patients with refractory frontal sinusitis after maximum medical treatment and primary frontal sinusotomy.[12] EMLP aims to create the largest possible anteroposterior and lateral diameters for the frontal neostium. In most cases, bilateral revised endoscopic sinus surgery and EMLP were performed simultaneously to remove the diseased nasal mucosa, which led to greater changes in the sinonasal structure and volume than primary endoscopic sinus surgery. Based on a literature review, the influence of these changes on nasal resonance after EMLP is not well understood or clearly explored. Therefore, the second aim of this study was to evaluate the changes in nasal resonance after EMLP and to explain the possible mechanism and relationship between nasal structure and resonance.

2. METHODS

2.1. Study setting

The institutional review board of MacKay Memorial Hospital approved this prospective study (17MMHIS106). We placed posters in a tertiary medical center to recruit healthy adults who volunteered to undergo nasalance analysis. Patients indicated for EMLP were referred by rhinologists at our medical center. Informed consent was obtained before commencement of the study.

2.4. Healthy participants

Healthy participants were enrolled as normative references for nasalance. The inclusion criteria were as follows: (1) adult native Mandarin speakers; (2) no history of craniofacial anomalies; (3) no history of oral and nasal surgery; (4) no symptoms of rhinosinusitis, such as nasal obstruction, purulent nasal discharge, dysosmia, headache, or facial pain over the past 1 month; and (5) no oral medications or nasal sprays to treat nasal obstruction, allergic rhinitis, or upper respiratory tract infection in the past 1 month.

2.5. EMLP patients

The inclusion criteria for EMLP patients were as follows: (1) adult native Mandarin speakers; (2) no history of craniofacial anomaly; (3) the diagnosis of refractory frontal sinusitis was made according to the 2012 European position paper on rhinosinusitis and nasal polyps (EPOS) criteria[13]; and (4) indications of undergoing bilateral revision endoscopic sinus and EMLP surgeries.

2.6. Passage speech stimuli

The oral-nasal passage stimuli consisted of 71 syllables, as modified by Jing-Yi Jeng,[14] and have been widely used in clinical practice in Taiwan. The oral passage stimuli contained 72 syllables.[15] While the original version of the oral passage stimuli contained 132 syllables, we used the first 72 syllables to ensure that each speech stimulus was equal in length. We also modified the phrase from/xən˘ ʂɑʊ˘ tɕjɑʊ˘/ to/pu xweɪ tɕjɑʊ/ to avoid the nasal sounds. The nasal speech stimuli were developed by Tsai et al.[15] We modified these stimuli using a combination of six sentences, each of which had seven syllables. We used a combination of sentences instead of passages to maximize the percentage of nasal sounds in the speech stimuli.

We translated these speech stimuli from Mandarin Phonic Symbols into the International Phonetic Alphabet. The percentage of nasal phonemes in each passage was determined by dividing the number of nasal phonemes by the total number of phonemes. The percentages of nasal phonemes were 0% (0/188) for the oral passage, 19.9% (41/206) for the oral-nasal passage, and 32.6% (45/138) for the nasal sentences.

2.7. Nasometer data collection

A Nasometer KayPENTEX II Model 6400 (Pentax Medical, Singapore) was used to analyze nasalance scores in this study. The nasometer was calibrated prior to data collection. The headgear and microphone headsets were configured according to the instructions provided in the 2008 edition of the nasometer guidebook.

Three speech stimuli were provided to the participants in a randomized order. The participants were asked to practice reading the passages before formal recording. The speaking rate and volume during recording were like those under normal speech conditions. If any sound interference or reading error occurred during the recording, the recording was stopped and repeated.

In the EMLP group, nasalance recordings were performed at three different time points: 1 day before the operation and 1 and 3 months after the operation.

2.8. Test-retest reliability

The test-retest comparison was conducted by randomly selecting 20% of the participants among healthy individuals to perform a second test. The selected participants rested for 20 minutes between the first and second recordings. The interclass correlation coefficient (ICC) between the first and second tests was analyzed for each speech stimulus.

2.9. Statistics

The mean nasalance scores for the three speech stimuli in healthy adults were compared using the one-way analysis of variance (one-way ANOVA) and multiple comparison post hoc method. Differences in nasalance scores between patients before the EMLP and healthy individuals were compared using t-tests. The preoperative and postoperative 1- and 3-month nasalance scores were compared using paired t-tests. Test-retest reliability was examined using the ICCs. Statistical significance was set at $p < 0.05$.

3. RESULTS

3.1. Nasalance of healthy Mandarin-speaking adults

A total of 101 healthy native Mandarin speakers (49 men and 52 women) between 20 and 65 years of age (mean=34.2 years) were enrolled. The nasalance scores of the 101 healthy Mandarin-speaking adults (mean ± SD) were 14.6% ± 6.7%, 39.4% ± 8.4%, and 55.8% ± 8.3% in the oral passage, oral-nasal passage, and nasal sentences, respectively. Nasalance differed significantly among the three speech stimuli ($\chi^2 = 202$, $p < 0.05$). The nasalance scores also differed significantly among the

speech stimuli: oral passage to oral-nasal passage ($p < 0.000$), oral passage to nasal sentences ($p < 0.000$), and oral-nasal passage to nasal sentences ($p < 0.000$).

3.2. Test-retest reliability

Twenty of the 101 healthy subjects (nine men and 11 women) performed a second recording. The overall ICC between the first and second recordings for the three speech stimuli was 0.968. The ICCs for each speech stimulus were as follows: 0.90 for oral passage, 0.79 for oral-nasal passage, and 0.85 for nasal sentences, respectively.

3.3. EMLP patients

A total of 21 patients (13 men, 8 women) ranging in age from 23 to 73 years (mean = 44 years) were included in this group. Two representative cases that underwent EMLP for refractory frontal sinusitis and frontal ostium restenosis are shown in Fig. 1. Preoperative paranasal sinus computed tomography revealed haziness in the bilateral frontal sinuses and narrowing of the bilateral frontal ostium in both the cases (Fig. 1A,D). In addition, an osteoma was found in the right frontal sinus in case 1 (Fig. 1A). The postoperative paranasal sinus computed tomography showed a large nasofrontal communication and a wide frontal ostium in both the cases (Fig. 1B,E). The postoperative sinoscopic view of the frontal sinuses showed wide-opened and well-epithelialized frontal neoostia (Fig. 1C,F).

The preoperative nasalance scores of the 21 EMLP patients were 23.2% ± 9.6%, 48.7% ± 10.7%, and 62.7% ± 10.9% for the oral passage, oral-nasal passage, and nasal sentences, respectively. The results of the three speech stimuli differed significantly in pairwise comparisons ($p < 0.05$, one-way ANOVA). The pre-EMLP nasalance scores were significantly higher than those of the healthy participants for the oral passage ($p < 0.05$, t-test), oral-nasal passage ($p < 0.05$, t-test), and nasal sentences ($p < 0.05$, t-test) (Fig. 2).

The post-EMLP nasalance scores at 1 and 3 months were 29.0% ± 9.3% and 29.9% ± 10.4% for the oral passage, 54.7% ± 7.7% and 56.4% ± 7.2% for the oral-nasal passage, and 69.8% ± 6.7% and 70.7% ± 6.4% for the nasal sentences, respectively. Significant increases in nasalance scores compared to pre-EMLP levels were observed for the three speech stimuli ($p < 0.05$, paired t-test). In addition, no statistically significant difference was observed between the nasalance scores at 1 and 3 months post-EMLP (Fig.3).

Fig. 4 shows an example of the long-term average spectra (LTAS) of the three speech stimuli from one healthy participant and one patient before and after the EMLP. For this healthy participant, the first peak depicted the fundamental frequency (F0) at 100 Hz and the second peak showed the first formant (F1) at 400 to 500 Hz. The patient with EMLP had an obvious nasal formant at 350 to 400 Hz, with the highest power level presented in nasal sentences. Compared with the preoperative power level, the power of the nasal formant for all the three stimuli increased significantly after surgery. In addition, an antinasal formant between 500 and 1000 Hz was found in EMLP patients, and the mean power level was lower than that of healthy participants. As such, in addition to changes in nasalance, the LTAS also showed differences after receiving EMLP, which included a higher power level of nasal formants and a lower power level of antinasal formants.

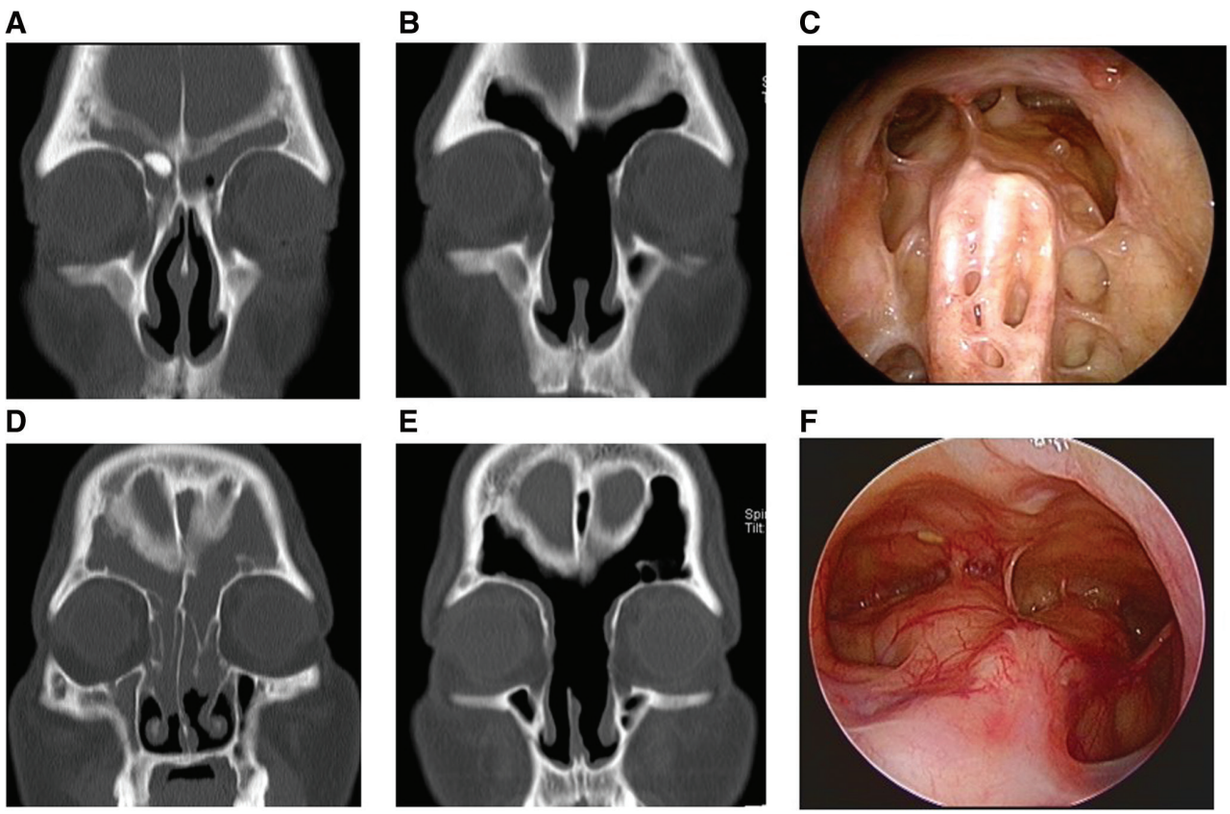

Fig. 1 Two representative cases of EMLP: the paranasal sinus CT before (A, D), after (B, E) EMLP, and the sinoscopic view after EMLP (C, F). A, B, C was the same patient, and D, E, F was another patient. CT = computed tomography; EMLP = endoscopic modified Lothrop procedure.

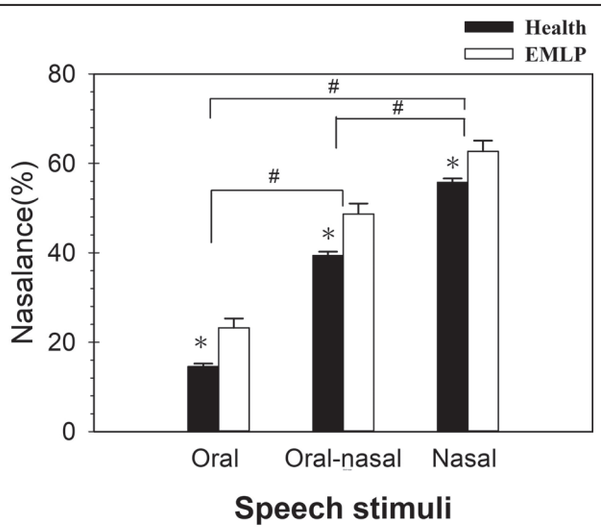

Fig. 2 Nasalance of the three speech stimuli for pre-EMLP patients and healthy participants ($p < 0.05$, marked as # and *). EMLP = endoscopic modified Lothrop procedure.

3.4. Harm and adverse events

The measurement of nasalance scores with a nasometer was a noninvasive examination; thus, no harm or adverse events occurred.

4.DISCUSSION

4.1. Standard speech stimuli

Previous studies have reported greater consistency[3] and higher test-retest reliability[2] for nasalance scores of continuous speech stimuli. There are norm nasalance references for connected-speech stimuli across several languages. However, Mandarin connected-speech stimuli have not been established for clinical applications. Therefore, we established Mandarin-connected speech stimuli for oral passage, oral-nasal passage, and nasal sentences, and the norm reference for nasalance scores for cross-sectional analysis. We compared these data with passage speech stimuli from other languages[16-20] (Table 1). The percentages of nasal phonemes in other studies were 0% for the oral passage, 8.6% to 31% for the oral-nasal passage, and 23.1% to 57.0% for the nasal sentences. The percentages of nasal phonemes in the speech stimuli in this study are consistent with those reported in nasalance studies in other languages.

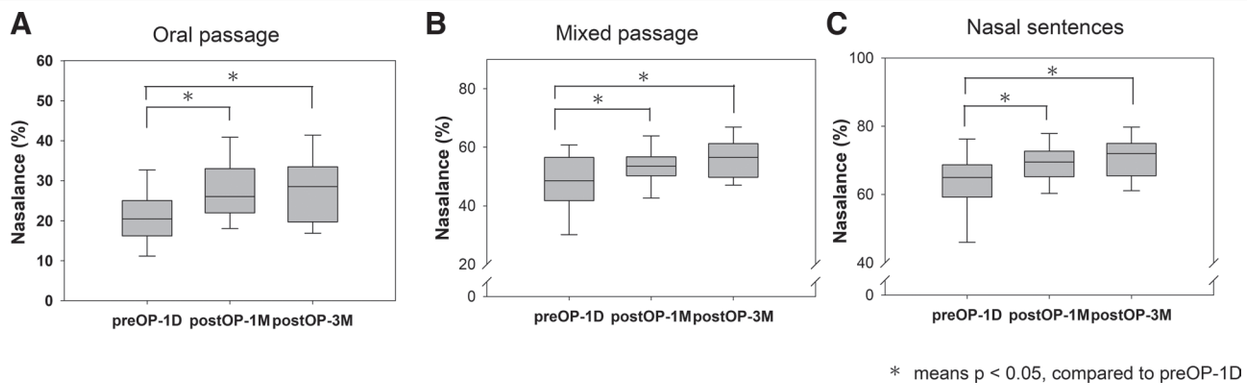

Fig. 3 Changes of nasalance for the three speech stimuli at pre-EMLP 1 day, post-EMLP 1 month and post-EMLP 3 months. ($p < 0.05$, marked as *). EMLP = endoscopic modified Lothrop procedure.

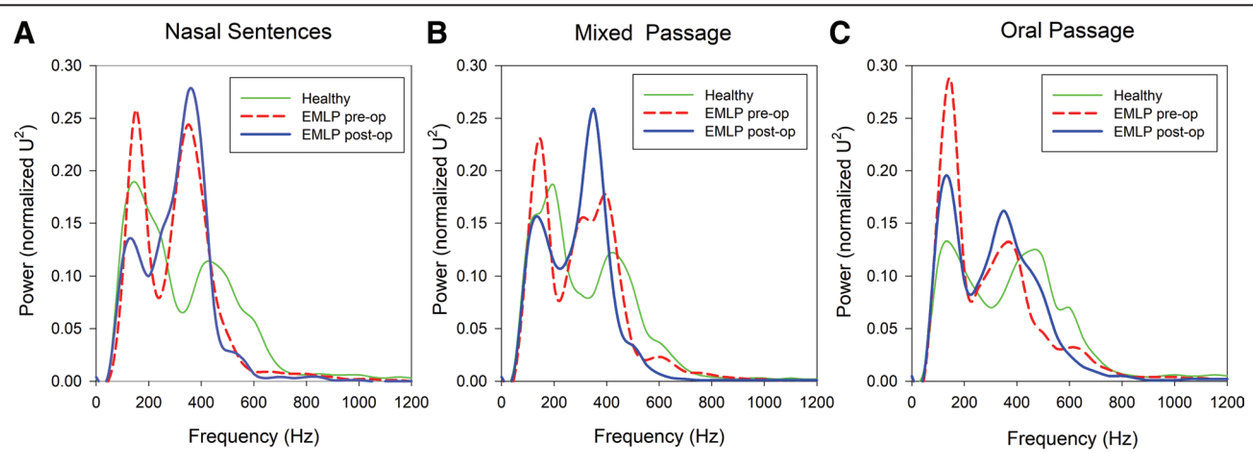

Fig. 4 The long-time average spectrum of the three stimuli for a healthy volunteer and a patient before and after receiving EMLP. A, nasal sentences; B, Mixed passage; C, Oral passage. EMLP = endoscopic modified Lothrop procedure.

Table 1

Norm reference of nasalance scores using passage stimuli and analyzed with Nasometer KayPENTAX 6400 for different languages

		Oral Passage			Oral-nasal Passage			Nasal Sentences		
Language/Study	No.[a]	N (%)[b]	Mean	SD	N (%)	Mean	SD	N (%)	Mean	SD
This study	101	0	14.56	6.69	19.9	39.43	8.40	32.6	55.80	8.34
Nasometer II Model 6400 guidebook (KayPENTAX, 2008)	40	0	11.25	5.63	11.5	31.47	6.65	35.0	59.55	7.96
Turkish[17]	125	0	13.46	6.26	16.0	37.84	6.13	29.5	50.28	7.77
Korean[20]	108	0	11.94	4.21	31.0	34.73	4.79	55.0	62.02	5.67
Portuguese[18]	62	0	Male 8.7	3.52	15.9	24.53	4.16	47.5	46.07	5.45
			Female 13.38	4.46		28.31	4.50		51.13	4.86

[a] No. = number of subjects in the study

[b] N (%) = the percentage of nasal phonemes in the speech stimuli

Mean: average of nasalance scores SD = standard deviation

4.2. Normative reference of nasalance scores

Table 1 presents the results of nasalance studies in different languages conducted with passage speech stimuli and the Nasometer KayPENTAX 6400. The nasalance scores in these studies ranged from 11.25% to 13.46% for the oral passage, 24.53% to 37.84% for the oral-nasal passage, and 46.07% to 62.02% for the nasal sentences. The nasalance scores of the nasal sentences in this study were within the above-mentioned range, while the nasalance scores were 1% to 2% higher in the oral-nasal passage compared to those in other studies. However, other studies reported the largest standard deviation (SD) in the nasalance scores of the nasal passages, whereas the oral-nasal passage showed the largest SD in our study. Kim et al[6] and Mishima et al[21] reported that the vowel/i/ showed the largest SD in the nasalance score. Ha and Cho[2] indicated that if the speech stimuli were mainly constructed with the vowel/i/, the SD would increase, despite the length of the speech stimuli. We divided the number of/i/ vowels by the total number of International Phonetic Alphabet phonemes to determine the percentage of/i/ vowels for each speech stimulus (oral passage, 13.8%; oral-nasal passage, 15.5%; and nasal sentences, 11.6%). The proportion of/i/ vowels was the highest for the oral-nasal passage, which may have resulted in a higher SD in the nasalance score.

The test-retest reliability was high in this study, which implies that the study settings and materials used could provide consistent results. We suggest that the method and speech stimuli in this study be used as standard study materials in further nasalance studies on Mandarin.

4.3. Changes in nasalance scores in patients undergoing the EMLP

Patients with refractory frontal sinusitis, even after maximum medical treatment and primary frontal sinusotomy, are indicated to undergo EMLP. EMLP was performed to communicate the bilateral frontal sinuses and widen the anterior-posterior and lateral diameters of the frontal ostium. Patients who underwent bilateral revised endoscopic sinus surgery and EMLP had greater changes in sinonasal anatomy and volume than those who underwent primary endoscopic sinus surgery and septomeatoplasty.

Previous studies showed increased nasalance scores at 1 month after sinonasal surgery,[1,5,6,22,23] which returned to the preoperative levels at 3 months after the operation.[1,22] However, Jiang and Huang[5] reported that changes in nasal resonance persisted for 6 months after endoscopic sinus surgery and concluded that the increase in nasalance scores did not correlate with the increase in nasal volume.

In our study, the pre-EMLP nasalance scores were higher than those of the norm references for the three speech stimuli. Since all the patients who were indicated for EMLP had undergone previous endoscopic sinus surgeries, we suggest that previous endoscopic sinus surgeries caused changes in the sinonasal structure and increased sinonasal volume, which subsequently led to increased nasal resonance in EMLP candidates.

The post-EMLP follow-up timing was set at one and three months postoperatively. In our clinical setting, clear sinus status could be achieved within 1 month of surgery by performing local treatment and nasal irrigation, while the re-epithelialization and recovery of the sinonasal mucosa after surgery required up to 3 months.[24] The nasalance scores at 1 and 3 months after the EMLP were both significantly increased compared to the pre-EMLP nasalance score, mainly due to changes in anatomic structures and increased sinonasal volumes. There was no significant difference between the nasalance scores at one and three months post-EMLP. Thus, we suggest that re-epithelialization and resolution of mucosal swelling had a minimal impact on nasal resonance. We also found that the LTAS of patients who underwent EMLP showed a higher power of nasal format and lower power of antinasal formant compared to that of the healthy subjects. In another study[25], we evaluated subjective changes in nasality after EMLP by using questionnaires. There were 47% of patients that had experienced changes in their voice.

In conclusion, EMLP had a significant impact on nasal resonance and voice spectrum, and the increase in nasalance lasted for at least three months. However, the long-term effects of EMLP on nasal resonance require further investigation.

The limitations of this study were that it did not include an evaluation of the nasal volume and resistance. Moreover, perceptual auditory evaluation of voice should be conducted to compare the subjective and objective changes in nasal resonance after EMLP.

The connected-speech stimuli in Mandarin and its norm reference nasalance scores can be used as standard materials for further Mandarin nasalance studies. The patients who underwent EMLP presented with hypernasality prior to surgery, which further increased at 1 and 3 months after EMLP. Changes in the sinonasal anatomy and volume after EMLP have an impact on nasal resonance.

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