INTRODUCTION

Cleft lip and palate (CLP) are common congenital anomalies with a prevalence of 1–2 births per 1000.1 When a cleft palate (CP) is present, the muscular insertions on the soft palate are abnormally configured. Surgery is aimed not only at closing the palatal defect but also at correcting this abnormal configuration by establishing continuity and proper muscular orientation.2

Abnormal facial growth is commonly seen in patients with CP.3 Repair of CP induces palatal scarring, which restricts growth of the maxilla in all directions, resulting in iatrogenic maxillary insufficiency. Correction of this maxillary retrusion is carried out 60% of the time in these patients,4 with the Le Fort I osteotomy being undertaken in almost 84% of them.5

During maxillary advancement (MA), there is concomitant advancement of the soft palate. This can lead to an increase in the space between the velum and the posterior pharyngeal wall. In patients without prior CP repair, this gap is usually compensated for by the lateral pharyngeal walls and the palatal musculature. Patients with CP are at a higher risk of velopharyngeal insufficiency because their scarred palatal musculature restricts this innate compensatory mechanism.6,7 So while orthognathic surgery has a potentially beneficial effect on speech due to the reestablishment of maxillomandibular equilibrium, it may contribute to the worsening of pre-existing hypernasality in patients with CP.8

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The use cephalograms in evaluating changes of airway size and shape MA has been extensively described. However, with recent advances in orthognathic surgery, there is an increased need for more detailed and precise imaging to help in surgical planning and to monitor response to treatment. Computerized Tomographic (CT) scans have the advantage of imaging structures in 3 dimensions, evaluating sagittal depth, transverse diameter, and pharyngeal airway volume. CT reconstructions have become crucial in surgical planning and yield superior surgical outcomes.

The purpose of this study was to document changes in airway anatomy, as measured on 3-Dimensional (3D) CT scans after Le Fort 1 MA. Additionally, differences in airway anatomy in patients with and without CP were compared. It was hypothesized that in patients undergoing MA, there are modifications in the structural anatomy of the naso- and oropharynx. But more specifically, it was hypothesized that although the dimensions of the pharyngeal space are modified, its surface area and volume do not change significantly.

**PATIENTS AND METHODS**

This was a retrospective single center cohort study of patients with and without CP who were treated with Le Fort 1 MA at our institution. This study was approved by the ethics committee at Sainte-Justine University Affiliated Hospital in Montreal.

**Subjects**

The inclusion criteria stipulated that subjects must have undergone: 1) Le Fort 1 MA at Sainte-Justine Hospital between 2012 and 2018, and 2) pre- and post-operative 3D CT scans after the top of the cranium to the base of the epiglottis. Both patients with and without a history of repaired CP were included. Patients aged under 16 years, and those who underwent craniofacial procedures that did not include Le Fort 1 MA or were lacking pre-operative or post-operative CT scans were excluded. Any syndromic patient was excluded.

**Surgical Procedure**

The surgical procedures for all subjects included in this study were done by the same plastic surgeon (D.B). All patients underwent a Le Fort 1 MA. Of the 44 patients included, 35 underwent concomitant bilateral sagittal split osteotomy setbacks.

**Image Acquisition**

All patients undergoing orthognathic surgery would undergo pre-operative CT scans for virtual surgical planning. These were all done within a year of the surgery, with most being between 1 and 3 months pre-operatively. Post-operative CT scans are routinely done at our institution. The most common time point for these was 3 days post-operatively (range, 1–365).

All subjects in the study underwent CT scans in the supine position with the head and neck in a neutral position and with the Frankfurt horizontal plane perpendicular to the ground. Images were acquired along the axial plane from the top of the cranium to the base of the epiglottis. The software used to reconstruct the images was Voxar. It allowed the following images to be computerized: 1) the original axial view, 2) coronal view, 3) sagittal view, and 4) 3D reconstruction.

**Image Analysis**

One author (ES) evaluated all CT images by identifying landmarks and by measuring linear distances, cross-sectional areas, and the nasopharyngeal volume. A second independent evaluator, who is a radiologist specialized in head and neck imaging (RJ), evaluated a subset of the CT images.

The landmarks and measurements were the same as those used by Gokce et al., Jakobsone et al., and Mason et al. The linear distances were calculated on the midsagittal plane through the nasal septum. The pre- and post-operative upper airway cross-sectional areas (CSAs) were studied at 2 levels identified on the midsagittal plane. On the corresponding axial image, the perimeter of the airway was traced with the cursor, and CSA was computed. Finally, to calculate the nasopharyngeal volume (NPV), the boundaries were set in the sagittal and coronal views, and the corresponding axial view was obtained. The parameter of the airway was traced with the cursor at 5 levels between the upper and lower boundaries, and the NPV was automatically calculated. The landmarks and measures are described in Table 1 and Figures 1–6.

The technique used for evaluation of the magnitude of maxillary advancement (MMA) was based on those used by Abramson et al., Lye et al., and Turvey et al. For MA and position, the true horizontal axis was defined as the sella-nasion line rotated 6 degree clockwise from the sella turcica (S). The posterior vertical reference line was a line passing through S and perpendicular to the true horizontal. The anterior vertical reference line was a line passing through point A (most concave point of anterior maxilla) and perpendicular to the true horizontal. The distance between anterior vertical reference line and posterior vertical reference line was measured before and after MA and is referred to as the MMA (in millimeters).

**Data Analysis**

Data analysis was done using SPSS Statistics, version 25. A 2-way mixed ANOVA was used to compare the mean differences between the groups (CP versus Non-CP), the mean differences in the pre- and post-operative measurements (within-groups), and to understand if there was an interaction between the group and surgery variables. That is, whether the differences seen over time (pre- and post-operative) varied depending on whether there was a history of prior CP repair.

A sub-group analysis was performed comparing those who underwent maxillomandibular surgery (MA + bilateral sagittal split osteotomy) with those who underwent MA alone. A Mann-Whitney U test was used to assess differences in RPa, RPa AP, and RPa LL between these two groups. Interrater reliability was assessed using an interclass correlation coefficient. A mean value of P < 0.05 was considered statistically significant for all analyses.
RESULTS

A total of 44 patients (24 men, 20 women) underwent MA at an average age of 20.3 years (range, 15–29 years). Twenty-three subjects had a prior CP repair. Of the 23 subjects, 6 had bilateral cleft lip and palate, 8 and 5 had left and right unilateral cleft lip and palate respectively, 1 had an isolated CP, and 3 had submucosal CP.

When comparing the average age at the time of surgery, there was no statistically significant difference between the two groups ($P = 0.392$). Looking at gender distribution, there was a clear discrepancy between the CP and Non-CP groups. There was a higher proportion of males in the CP group (73.9%), whereas that of females in the non-CP group was higher (66.6%), a difference that was statistically significant ($P = 0.007$) (Table 2).

The mean maxillary advancement for the CP group was 6.2 mm, while for the non-CP group it was 4.2 mm. This difference was not statistically significant ($P = 0.571$) (Table 2).

The average delay between the pre-operative scan and surgery was 74.4 (range, 28–208) for the CP group and 99.5

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**Table 1. Landmarks, Linear Distances, Cross Sectional Areas, and Volumetric Space Assessed on CT Scans**

| Description                  | Definition                                                                 |
|------------------------------|-----------------------------------------------------------------------------|
| Landmarks                    |                                                                             |
| PNS                          | Posterior nasal spine                                                       |
| UPW                          | Upper pharyngeal wall                                                       |
| NPW                          | Narrowest pharyngeal wall                                                   |
| RV                           | Retro velar                                                                 |
| Distances                    |                                                                             |
| PNS-UPW                      | Narrowest part of the nasopharynx                                            |
| RV-NPW                       | Narrowest part of the retropalatal airway space                              |
| V                            | Volar length                                                               |
| VT                           | Volar thickness                                                            |
| RPa AP                       | Anteroposterior distance at the RPa                                        |
| RPa LL                       | Latero-lateral distance at the RPa                                           |
| Areas                        |                                                                             |
| NPa                          | Nasopharyngeal cross-sectional area                                         |
| RPa                          | Retropalatal cross-sectional area                                           |
| Volume                       |                                                                             |
| NPV                          | Nasopharyngeal volume                                                       |

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**Fig. 1.** Linear distances assessed on sagittal reconstruction, using a CT scan.
(range, 20–390) for the non-CP group. For timing of the post-operative scans, the mean number of days for the CP group was 21.7 (range, 1–365) and for the non-CP group it was 12.5 (range, 1–128). These differences were not statistically significant (\( P = 0.533 \) and 0.808, respectively).

For the linear distances computed, PNS-UPW distance went from 25.1 mm in the pre-operative period to 28.5 mm post-operatively (\( P = 0.001 \)). Of the remaining linear distances measured, a statistically significant difference was found when comparing the pre- and post-operative measures of the RV-NPW (6.5 mm versus 7.6 mm, \( P = 0.026 \)), VT (8.2 mm versus 9.6 mm, \( P = 0.031 \)) and RPa AP (7.5 mm versus 8.6 mm, \( P = 0.013 \)) distances (Table 3).

After surgery, no statistically significant changes in the cross-sectional areas were recorded. No change was observed for the NPa (pre: 375.2 mm\(^2\) versus post: 370.4 mm\(^2\), \( P = 0.435 \)) and RPa (pre: 129.8 mm\(^2\) versus post: 145.7 mm\(^2\), \( P = 0.525 \)). There was also no statistically significant difference in the pre- and post-operative measurements of the NPV (4.1 cm\(^3\) versus 4.3 cm\(^3\), \( P = 0.401 \)) (Table 4).

The main effect of palatal repair (CP versus Non-CP) showed that there was only a statistically significant difference for the PNS-UPW and NPa measures (\( P = 0.045 \) and \( P = 0.04 \), respectively). There were no statistically significant interactions between time and group. That is, mean
changes in the measures did not differ over time (pre- and post-operative) depending on whether there was prior history of CP repair.

Differences in pre-to post-operative change for the RPa, RPa AP, and RPa LL measures between those who underwent MA with or without concomitant mandibular repositioning were computed. For the RPa LL distance change, a statistically significant difference was found between the mean increase of 2.98 mm in the MA group alone and the mean decrease of 1.77 mm in the maxillomandibular surgery group ($P = 0.027$). No change was noted between the two groups for the RPa and RPa AP measures ($P = 0.104$ and $P = 0.647$, respectively).

On all 88 scans (44 patients), measures were assessed by a single evaluator (E.S.). A second independent evaluator (R.J.) used the same technique to measure 20 randomly selected scans (10 patients). The interclass correlation coefficient was 0.989.

**DISCUSSION**

The purpose of this study was to evaluate the changes to the velopharyngeal anatomy after MA using 3D CT scans. In addition, the differences in these measures between patients with and without prior CP repair were compared. Several studies have measured surface areas and volumes of the nasopharynx, oropharynx, and hypopharynx...
following MA using CT scans. However, there is no clear consensus as to the morphological changes seen following MA. MA is performed when patients have completed their maxillofacial growth to obtain reliable and predictable results. Average age of the combined groups at the time of surgery was 20.3 years. Schendel et al. demonstrated progressive enlargement of the posterior airway in childhood until age 15. Given that all included patients were older than 16 years, this possible source of bias was eliminated. There was no difference in age at the time of surgery between the CP and non-CP groups.

Maegwa et al. separated patients into 1 of 2 categories based on the amount of maxillary advancement performed. Advancements up to 10 mm were associated with maintaining baseline or improving speech intelligibility, whereas advances above 10 mm were associated with decreased intelligibility and hypernasality. Despite these described complications, there are many benefits to MA. Apart from aesthetic facial improvement, this surgery has also been proven to improve mood, affect, social interactions, and speech ability. The mean maxillary advancement for the CP group was 6.18 mm and 4.24 mm for the non-CP group. With a relatively limited amount of advancement in the present study compared with up to 12.4 mm in some, significant changes in surface areas and volumes were not expected.

The literature assessing structural airway changes in patients undergoing MA is limited. The majority of published studies focus primarily on the structural changes to the airway, with only a few examining changes in surface areas and volumes. Two-way mixed ANOVA was used to compare the mean differences between the groups (CP versus Non-CP) and the mean differences in the pre- and post-operative measurements (within groups). The interaction P value reflects whether differences seen over time (pre- and post-operative) varied depending on the groups.
the airway and their impact on patients with obstructive sleep apnea. To the best of our knowledge, the anatomical changes of the velum studied on CT scans have yet to be reported. Patients with no history of CP have the ability to compensate for the structural changes following MA, which prevents any adverse effects on velopharyngeal closure function and speech. Cephalometric analyses of these changes have been reported but published results are inconsistent. Ko et al. described these changes as increases in nasopharyngeal depth, VL, and velar angle, and a decrease in VT. Wu et al. reported an increase in VL with no change in VT. In this study, the anatomical changes to the velum, VL and VT, were assessed using CT scans. Although VL did show a trend toward an increase from the pre-operative period to the post-operative period, this change was not significant. This is consistent with the reports by Ko et al. and Heliovaara et al. Furthermore, the difference in VL from the pre-to the post-operative period was independent of whether or not patients had a prior CP repair. A significant increase was noted when comparing the pre- and post-operative measures of VT.

While a decrease in VT due to velar stretch may have been expected, the increase noted may be attributed to post-operative edema, as most scans were completed in the acute post-operative period.

We found a statistically significant increase in the linear distance RV-NPW (P = 0.026) following MA. Similarly, the RP a AP distance significantly increased following MA (P = 0.013). Chang et al. and Gokce et al. both described similar findings reporting an increase in the AP distance between the soft palate and posterior pharyngeal wall. Gokce et al. also reported a statistically significant increase in the PNS-UPW distance, which was consistent with our findings. These changes are attributed to anterior displacement of the maxilla and the subsequent pull on the velum and velopharyngeal muscles following the Le Fort I osteotomy.

It was thought that with advancement of the maxilla and the velum, the lateral pharyngeal walls would compensate to maintain an unchanged overall area and volume. For instance, Kumer et al. used videofluoroscopy and reported increased motion of the lateral pharyngeal walls.
following MA. The LL distance at the level of RV-NPW was used to assess this change. Although not statistically significant, a trend toward a decrease was noted. This is however not consistent with other studies reporting an increase in the LL distance. We then compared those who underwent exclusive MA with those who underwent MA with concomitant mandibular setback and noticed a significant difference in the RPa LL distance. While those who underwent exclusive MA saw an average increase of 2.98 mm, those who underwent a maxillomandibular surgery actually saw an average decrease of 1.77 mm. Degerliyurt et al. led a study comparing the structural airway changes between patients who underwent exclusive mandibular setback and patients who underwent maxillomandibular surgery. They found that lateral pharyngeal narrowing was only statistically significant in the mandibular setback group. They attributed this difference to the displacement of the medial pterygoid muscles caused by the mandibular setback. Our findings are thus similar and show that maxillary surgery might counteract the reduction in lateral width, which is an effect of mandibular setback.

Although changes in AP and LL distances were seen, the overall surface area measures did not change significantly in our sample. Similarly, Jakobsone et al. found no statistically significant change in VP CSA after MA. Abramson et al. did report an increase in the minimum VP CSA after MA. However, their mean maxillary advancement was of 9.2 mm, which is significantly higher than that of the present study. The relatively limited MMA in our study perhaps explains the lack of a statistically significant change when comparing the pre- and post-operative measures. When analyzing the difference in NPV between the two study groups, it was significantly smaller in the non-CF group both pre- and post-operatively. This change was likely a reflection of the significant difference in the PNS-UPW distance between the two study groups.

With respect to NPV, no statistically significant difference was observed. Chang et al. and Gokee et al. both reported statistically significant increases in NPV following MA surgery. Jakobsone et al. found no significant change in NPV following MA but rather reported a trend toward a decrease. Aras et al. led a study using CT scans to measure and compare total airway volume in patients with and without CP. Although there was a decrease in the volume in patients with CP due to the scar tissue contracture, it was not statistically significant.

Several limitations are worth noting in this study. First, due to its retrospective nature, there were no instructions given to the patients during the CT scans. Therefore, there was no standardization of verbal guidance in terms of holding their breath, swallowing, or proceeding normally. Similarly, CT scans offer only a static evaluation of a dynamically functional structure. So, while airway size, shape, and dimensions may be an indicator for residual velopharyngeal insufficiency, they do not substitute for a dynamic assessment of velopharyngeal closure.

Another limitation is that all scans were performed at the same time pre- and post-operatively. Due to the acute post-operative timing of the scans, the presence of edema may have introduced bias to the results. Having the scans done at standardized time frames minimizes bias and makes the obtained results more comparable. Finally, the procedures were not uniform amongst the 44 included patients. While the majority underwent maxillomandibular surgery, a subset of patients underwent exclusive MA. The mixture of data may have introduced certain bias to the results.

**CONCLUSIONS**

The goal of the present study was to identify useful anatomic and morphologic changes to the velopharyngeal space following MA. The use of 3D reconstruction using CT scans should be the first choice for evaluation of the upper airway. Not only does it provide the surgeon with an understanding of the underlying anatomical structures during pre-operative planning, it also allows for assessment of structural changes following surgery. These changes serve as key indicators for functional outcomes. Future studies should correlate these anatomic results to dynamic velopharyngeal function assessments and development of velopharyngeal insufficiency.

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**PATIENT CONSENT**

_The patient provided written consent for the use of his image._

**REFERENCES**

1. Hagberg C, Larson O, Milrad J. Incidence of cleft lip and palate and risks of additional malformations. _Cleft Palate Craniofac J._ 1998;35:40–45.
2. Costello BJ, Ruiz RL, Turvey TA. Velopharyngeal insufficiency in patients with cleft palate. _Oral Maxillofac Surg Clin North Am._ 2002;14:539–551.
3. Pereira VJ, Sell D, Tuomainen J. Effect of maxillary ostectomy on speech in cleft lip and palate: perceptual outcomes of velopharyngeal function. _Int J Lang Commun Disord._ 2013;48:640–650.
4. Hathaway R, Daskalogiannakis J, Mercado A, et al. The American cleft study: an inter-center study of treatment outcomes for patients with unilateral cleft lip and palate part 2. Dental arch relationships. _Cleft Palate Craniofac J._ 2011;48:244–251.
5. Cheung LK, Chua HD. A meta-analysis of cleft maxillary ostectomy and distraction osteogenesis. _Int J Oral Maxillofac Surg._ 2006;35:14–24.
6. Smedberg E, Neovius E, Lohmander A. Impact of maxillary advancement on speech and velopharyngeal function in patients with cleft lip and palate. _Cleft Palate Craniofac J._ 2014;51:334–343.
7. McComb RW, Marrinan EM, Nuss RC, et al. Predictors of velopharyngeal insufficiency after Le Fort I maxillary advancement in patients with cleft palate. _J Oral Maxillofac Surg._ 2011;69:2226–2232.
8. Trindade IE, Yamashita RP, Sugimoto RM, et al. Effects of orthognathic surgery on speech and breathing of subjects with cleft lip and palate: acoustic and aerodynamic assessment. _Cleft Palate Craniofac J._ 2003;40:54–64.
9. Aksu M, Taner T, Sahin-Veske P, et al. Pharyngeal airway changes associated with maxillary distraction osteogenesis in adult cleft lip and palate patients. *J Oral Maxillofac Surg*. 2012;70:e133–e140.

10. Efanon JL, Roy AA, Huang KN, et al. Virtual surgical planning: the pearls and pitfalls. *Plast Reconstr Surg Glob Open*. 2018;6:e1443.

11. Chang CS, Wallace CG, Hsiao YC, et al. Airway changes after cleft orthognathic surgery evaluated by three-dimensional computed tomography and overnight polysomnographic study. *Sci Rep*. 2017;7:12260.

12. Hanasono MM, Skoracki RJ. Computer-assisted design and rapid prototype modeling in microvascular mandible reconstruction. *Laryngoscope*. 2013;123:597–604.

13. Gokce SM, Gorgulu S, Gokce HS, et al. Evaluation of pharyngeal airway space changes after bimaxillary orthognathic surgery with a 3-dimensional simulation and modeling program. *Am J Orthod Dentofacial Orthop*. 2014;146:477–492.

14. Jakobsone G, Neimane L, Krumina G. Two- and three-dimensional evaluation of the upper airway after bimaxillary correction of Class III malocclusion. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2010;110:234–242.

15. Mason KN, Perry JL. Relationship between age and diagnosis on volumetric and linear velopharyngeal measures in the cleft and noncleft populations. *Cleft Craniofac J*. 2016;27:1340–1345.

16. Abramson Z, Susarla SM, Lawler M, et al. Three-dimensional computed tomographic airway analysis of patients with obstructive sleep apnea treated by maxillomandibular advancement. *J Oral Maxillofac Surg*. 2011;69:677–686.

17. Lyte KW, Waite PD, Wang D, et al. Predictability of prebent advancement plates for use in maxillomandibular advancement surgery. *J Oral Maxillofac Surg*. 2008;66:1625–1629.

18. Turvey TA, Bell RB, Phillips C, et al. Self-reinforced biodegradable screw fixation compared with titanium screw fixation in mandibular advancement. *J Oral Maxillofac Surg*. 2006;64:40–46.

19. Fu Z, Lin Y, Ma L, et al. Effects of maxillary protraction therapy on the pharyngeal airway in patients with repaired unilateral cleft lip and palate: a 3-dimensional computed tomographic study. *Am J Orthod Dentofacial Orthop*. 2016;149:673–682.

20. Aras I, Olimez S, Dogan S. Comparative evaluation of nasopharyngeal airways of unilateral cleft lip and palate patients using three-dimensional and two-dimensional methods. *Cleft Palate Craniofac J*. 2012;49:e75–e81.

21. Degerliyurt K, Ueki K, Hashiba Y, et al. A comparative CT evaluation of pharyngeal airway changes in class III patients receiving bimaxillary surgery or mandibular setback surgery. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2008;105:495–502.

22. Schendel SA, Jacobson R, Khalesi S. Airway growth and development: a computerized 3-dimensional analysis. *J Oral Maxillofac Surg*. 2012;70:2174–2183.

23. Maegawa J, Sells RK, David DJ. Speech changes after maxillary advancement in 40 cleft lip and palate patients. *J Craniofac Surg*. 1998;9:177–182; discussion 183-174.

24. Harada K, Ishii Y, Ishii M, et al. Effect of maxillary distraction osteogenesis on velopharyngeal function: a pilot study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2002;93:538–543.

25. Heliovaara A, Ranta R, Hukki J, et al. Cephalometric pharyngeal changes after Le Fort I osteotomy in patients with unilateral cleft lip and palate. *Acta Odontol Scand*. 2002;60:141–145.

26. Bevilacqua RG, Ritioli EL, Kang C, et al. Midmaxillary internal distraction osteogenesis: ideal surgery for the mature cleft patient. *Plast Reconstr Surg*. 2008;121:1768–1778.

27. Mochida M, Ono T, Saito K, et al. Effects of maxillary distraction osteogenesis on the upper-airway size and nasal resistance in subjects with cleft lip and palate. *Oral Surg Craniofac Res*. 2004;7:189–197.

28. Zinner MJ, Zachow S, Haider HF. Bimaxillary ‘rotation advancement’ procedures in patients with obstructive sleep apnea: a 3-dimensional airway analysis of morphological changes. *Int J Oral Maxillofac Surg*. 2013;42:569–578.

29. Hsieh YJ, Liao YF, Chen NH, et al. Changes in the calibre of the upper airway and the surrounding structures after maxillo-mandibular advancement for obstructive sleep apnoea. *Br J Oral Maxillofac Surg*. 2014;52:445–451.

30. Schwarz C, Gruener E. Logopaedic findings following advancement of the maxilla. *J Oral Maxillofac Surg*. 1976;4:49–55.

31. Ko EW, Figueroa AA, Guyette TW, et al. Velopharyngeal changes after maxillary advancement in cleft patients with distraction osteogenesis using a rigid external distraction device: a 1-year cephalometric follow-up. *J Craniofac Surg*. 1999;10:312–320; discussion 321.

32. Wu Y, Wang X, Ma L, et al. Velopharyngeal configuration changes following Le Fort I osteotomy with maxillary advancement in patients with cleft lip and palate: a cephalometric study. *Cleft Palate Craniofac J*. 2015;52:711–716.

33. Heliovaara A, Hukki J, Ranta R, et al. Cephalometric pharyngeal changes after Le Fort I osteotomy in different types of clefts. *Scand J Plast Reconstr Surg Hand Surg*. 2004;38:5–10.

34. Kummer AW, Strife JL, Grau WH, et al. The effects of Le Fort I osteotomy with maxillary advancement on articulation, resonance, and velopharyngeal function. *Cleft Palate J*. 1989;26:193–199; discussion 199.

35. Kawamata A, Fujishita M, Arijy Y, et al. Three-dimensional computed tomographic evaluation of morphologic airway changes after mandibular setback osteotomy for prognathism. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2000;90:278–287.

36. Samman N, Tang SS, Xia J. Cephalometric study of the upper airway in surgically corrected class III skeletal deformity. *Int J Adult Orthodont Orthognath Surg*. 2002;17:180–190.

37. McCarthy JG, Coccaro PJ, Schwartz MD. Velopharyngeal function following maxillary advancement. *Plast Reconstr Surg*. 1979;64:180–189.

38. Shprintzen RJ, Sher AE, Croft CB. Hypernasal speech caused by tonsillar hypertrophy. *Int J Pediatr Otorhinolaryngol*. 1987;14:45–56.

39. Gereau SA, Shprintzen RJ. The role of adenoids in the development of normal speech following palatoplasty. *Laryngoscope*. 1988;98:299–303.