American Cleft Palate–Craniofacial Association

Original Article

The Cleft Palate-Craniofacial Journal
2019, Vol. 56(10) 1314-1321

DOI: 10.1177/1055665619852562
journals.sagepub.com/home/cpc
SAGE

# Predictors of Velopharyngeal Dysfunction in Individuals With Cleft Palate Following Surgical Maxillary Advancement: Clinical and Tomographic Assessments

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## Abstract

*Objective:* To investigate whether morphofunctional velopharyngeal aspects may be considered predictors of appearance or worsening of hypernasality in patients with cleft palate after surgical maxillary advancement (MA).

*Design:* Prospective.

*Setting:* National referral center for cleft lip and palate rehabilitation.

*Participants:* Fifty-two patients with repaired cleft palate, skeletal class III malocclusion, and normal speech resonance completed speech audio recordings and cone-beam computed tomography examination before (T1) and, on average, 14 months after (T2) MA.

*Interventions:* Hypernasality was rated by 3 experienced speech-language pathologists using a 4-point scale and morphofunctional aspects on a 3-point scale. Cone-beam computed tomography image measurements were performed using Amira and Dolphin 3D software. For each velopharyngeal morphofunctional aspect analyzed, patients were compared according to the absence (G1) and presence (G2) of postoperative hypernasality.

*Main Outcome Measures:* Comparison of hypernasality scores between T1 and T2 and association between hypernasality and each velopharyngeal morphofunctional aspect.

*Results:* Significant difference was observed between T1 and T2 for hypernasality ( $P = .031$) and between G1 and G2 ( $P = .015$) for velar mobility, with significant association between this variable and hypernasality on T2 ($P = .041$).

*Conclusions:* Levator veli palatini mobility influenced the appearance of hypernasality after MA.

### Keywords

cleft palate, velopharyngeal insufficiency, speech perception, orthognathic surgery

## Introduction

Deficient growth of the midface is often observed in individuals with cleft lip and palate. Cases with marked maxillomandibular discrepancy require orthognathic surgery for repositioning of bone bases at completion of orthodontic treatment (Trindade et al., 2003; Freitas et al., 2012; Pereira, 2012; Wu et al., 2015). This surgical procedure is used in 10% to 50% of individuals with cleft lip and palate (Good et al., 2007; Daskalogiannakis and Mehta, 2009; Broome et al., 2010; Pereira, 2012; Smedberg et al., 2014; Wu et al., 2015) and, among the several surgical techniques, Le Fort I osteotomy for maxillary advancement (MA) is the most commonly

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used surgical approach in this population. This procedure may be performed by fracture of 1 to 4 segments and allows horizontal, vertical, and transverse movements (Scartezini et al., 2007). It may also be performed in isolation or combined with sagittal mandibular osteotomy and chin osteotomy (Kim et al., 2012; Faria et al., 2013).

The impact of orthognathic surgery with MA on the speech and velopharyngeal function has been analyzed by several studies along the years (Schendel et al., 1979; Witzel et al., 1988; Pereira et al., 2013a; Kudo et al., 2014; Smedberg et al., 2014; Karabekmez et al., 2015). This has encouraged the investigators to analyze, among other aspects, the possible factors influencing the appearance or worsening of speech symptoms, such as hypernasality, after surgical MA.

In an attempt to identify the aspects that may impair the speech resonance after orthognathic surgery, studies have employed instrumental examinations such as nasometry and pressure-flow technique (Trindade et al., 2003), nasopharyngoscopy (Phillips et al., 2005; McComb et al., 2011), and electromyography of levator veli palatini muscle (Nohara et al., 2006). In addition, analysis of surgical models to assess the extent of anteroposterior movement of the maxilla (Phillips et al., 2005) and analysis of cephalometric radiographs to assess the palatal thickness and length and the nasopharyngeal depth (McComb et al., 2011) were also investigated.

This study investigated if the aspects related to velopharyngeal function, perceptually analyzed in the clinical practice, offer greater risk of appearance or worsening of hypernasality after surgical MA.

The study hypothesis was that MA, combined with unfavorable aspects related to the palatal length, mobility and insertion of levator veli palatini muscle, and nasopharyngeal depth, may lead to the appearance or worsening of hypernasality, the main symptom of velopharyngeal dysfunction. The present results will allow the speech-language pathologists, during preoperative evaluation, to identify the patients at greater risk of speech worsening after surgery, which is an important contribution for the clinical practice.

## Material and Methods

This study was conducted according to the principles stated in the Declaration of Helsinki "Ethical Principles for Medical Research Involving Human Subjects." The study was reviewed and approved by the institutional review board.

### *Participants*

A total of 52 adult male and female patients with repaired cleft palate aged 18 to 34 years (mean: 23.7 $\pm$ 4.2 years) participated in this study. The participants included 38 patients with unilateral cleft lip and palate, 11 with bilateral cleft lip and palate (BCLP), and 3 patients with isolated cleft palate. All patients underwent surgical MA performed by the same surgeon to correct maxillomandibular discrepancy. As an inclusion criteria, all patients presented anterior crossbite with a negative overjet of, at least, 1 mm and normal speech resonance (absence of hypernasality) or mild hypernasality before surgery. All patients underwent a cone-beam computed tomography (CBCT) examination and speech audio recording before (T1) and, on average, 14 months after surgery (T2). Additionally, patients completed a video recording of the soft palate at rest and on movement before surgery.

**Table 1.** Description of Bone Structures Used as Reference for the Superimposition of Pre- and Postoperative CBCT Images, According to the Anatomical Plane.

| Anatomical Plane | Reference Points |
|---|---|
| Axial | 1. Occipital bone (basilar portion—clivus) |
| Coronal | 2. Parietal bone |
| | 3. Temporal bone (zygomatic process) |
| Sagittal | 4. Frontal bone (lower anterior portion) |
| | 5. Nasal bone (upper portion) |
| | 6. Sphenoid bone (pituitary fossa—sella turcica) |
| | 7. Occipital bone (basilar portion—most anterior and lower portion of the foramen magnum) |

Abbreviation: CBCT, cone-beam computed tomography.

### *Cone-Beam Computed Tomography Imaging*

All CBCT images were taken with patients in upright position (Frankfort plane parallel to the floor), using 2 machines: i-CAT Next Generation (Imaging Sciences International, Hatfield, Pennsylvania, version 11.8) with parameters for image acquisition set at 120 kV, 37.10 mA, field of view (FOV) 17 $\times$ 23 cm, and voxel size 0.4 mm; and 3D Accuitomo 170 (J Morita Mfg. Corp, Kyoto, Japan) at 90 kV, 7 mA, FOV 17 $\times$ 12, and voxel size 0.33 mm.

The CBCT images, stored in DICOM format (Digital Imaging and Communications in Medicine), were visualized and analyzed using specific softwares to assure the maintenance of their original anatomical proportions (Perry et al., 2016; Kotlarek et al., 2017).

*Maxillary advancement measurement.* The total extent of MA was obtained by superimposition of pre- and postoperative CBCT images using the software *Dolphin 3D* (Dolphin Imaging & Management Solutions, Chatsworth, California, version 11.8). The study took as reference the contours of the skull bones that are not influenced by the Le Fort I osteotomy, considering the bone structures in the 3 different anatomical planes (Table 1).

The total extent of MA obtained for each patient was determined according to the distance between points "A" on the pre- and postoperative images (point of maximum concavity of the midline in the maxillary alveolar process) detected on the sagittal plane of the 2 tomographies, considering up to 7 mm = advancement of smaller magnitude and >7 mm = advancement of greater magnitude (Figure 1).

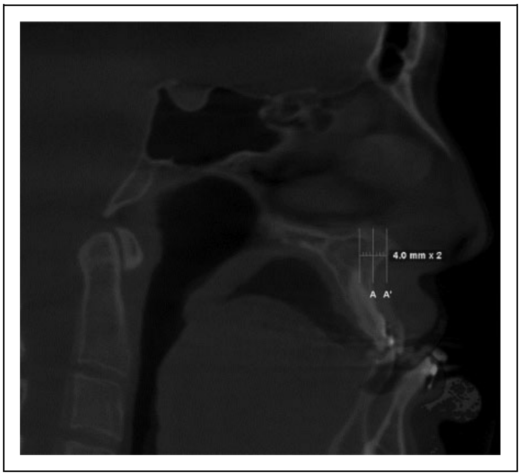


**Figure 1.** Measurement of distance between points "A" and "A′" determined on the pre- and postoperative tomographic images, using the ruler tool.

*Procedures for measuring velopharyngeal structures.* The measurements of palatal length and nasopharyngeal depth were obtained by analysis of CBCT images at moment T1 (52 images), using the software *Amira Visualization and Volume Modeling* (Thermo Fisher Scientific, Waltham, Massachusetts, version 5.6). The lowermost border of the palate was taken as reference to achieve the values of length of soft palate and nasopharyngeal depth (Medeiros et al., 2017).

The measurement of the nasopharyngeal depth was based on the palatal plane, by calculation of the distance between the lowermost border of the palate and the point at which the palatal plane tracing intersected the posterior pharyngeal wall. The measurement of palatal length is the value of the distance between the lowermost border of the palate and the tip of the uvula. Based on these 2 measurements, the ratio of nasopharyngeal depth was calculated, considering as criteria for scoring as adequate or inadequate velopharyngeal closure the values previously established in the literature (Satoh et al., 2005; Lu et al., 2006).

## Intraoral Recordings

The intraoral images were obtained by video recording at T1 using a professional digital camera connected to an illuminator. To achieve the recordings, the patient remained seated with maximum mouth opening and tongue resting on the mouth floor, allowing observation of its entire extent. These recordings were conducted with the palate in physiological rest to analyze the palatal length (Figure 2) and in movement, during repetition of /a/, in order to analyze the mobility and insertion of levator veli palatini muscle (Figure 3).

## Speech Sample Recordings

Video recordings were performed of reading of 12 sentences, containing predominantly oral sounds, using a professional camera in a quiet environment, with the patient seated at approximately 1 m from the camera. Thereafter, the speech recordings were converted to audio and edited, excluding the participation of the examiner.

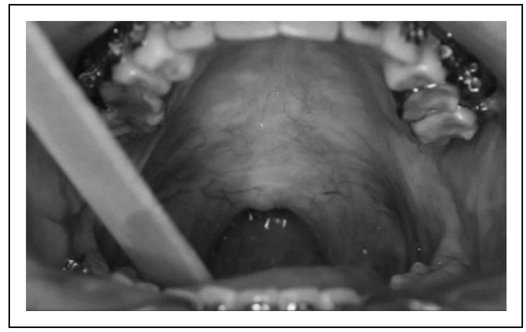

**Figure 2.** Image representing the registry for scoring of palatal length at rest.

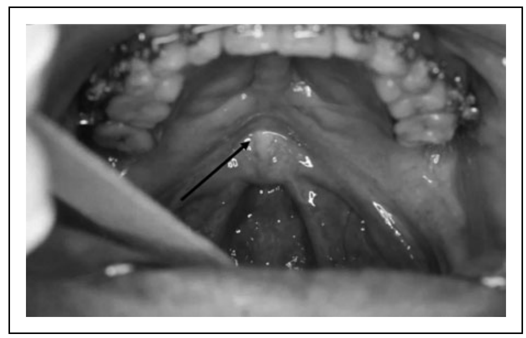

**Figure 3.** Image representing the registry for scoring of mobility and insertion of the levator veli palatini muscle (indicated by the arrow) during emission of vowel /a/.

**Table 2.** Criteria for Scoring of Morphological and Functional Aspects of the Palate and Speech Resonance of Individuals.

| Evaluated Aspect | Classification Scores | | | |
|---|---|---|---|---|
| Morphological and functional | | | | |
| Palatal length | 1 = long | 2 = regular | 3 = short | |
| Levator veli palatini mobility | 1 = good | 2 = regular | 3 = poor | |
| Levator veli palatini insertion | 1 = posterior | 2 = middle | 3 = anterior | |
| Speech resonance | | | | |
| Hypernasality | 1 = absent | 2 = mild | 3 = moderate | 4 = severe |

## Perceptual Analysis by Examiners

The scoring of morphofunctional aspects of the palate and speech hypernasality was individually performed by 3 experienced speech-language pathologists. If there was no agreement between examiners, the final result for each variable was obtained by consensus. The samples were scored and classified based on representative models of each parameter analyzed (anchors), previously defined according to the criteria described in Table 2.

**Table 3.** Distribution of Patients (Number and Percentage) of Groups G1 and G2 According to the Scores Determined by Perceptual Analysis Performed by the Examiners, for the Morphological and Functional Aspects of the Palate.[a]

| | G1 (n = 41) | | | G2 (n = 11) | | | |
|---|---|---|---|---|---|---|---|
| Variable | 1 | 2 | 3 | 1 | 2 | 3 | *P* |
| Length | 4 (10%) | 21 (51%) | 16 (39%) | 0 (0%) | 6 (54.5%) | 5 (45.5%) | .513 |
| Mobility | 18 (43.9%) | 20 (48.8%) | 3 (7.3%) | 1 (9%) | 7 (64%) | 3 (27%) | .015[b] |
| Insertion | 8 (19.5%) | 3 (27.3%) | 13 (31.7%) | 3 (27.3%) | 20 (48.8%) | 5 (45.4%) | .763 |

Abbreviations: G1, patients without hypernasality after surgery; G2, patients with hypernasality after surgery.
[a]Comparison between groups per variable—Mann-Whitney *U* test.
[b]Statistically significant difference ($P = .015$).

### *Statistical Analyses*

The analyses of all CBCT images were carried out by a single investigator trained in 3-dimensional imaging analysis. The intrarater reliability was examined using all images (100%) remeasured 2 weeks apart. The systematic errors were calculated by application of the paired *t* test, and the casual errors were estimated by application of the Dahlberg formula. The intraclass correlation coefficient was calculated considering the following interpretation: $\leq 0.40$ = poor to fair; 0.41 to 0.75 = moderate; $>0.75$ = good.

To analyze the data of hypernasality, scores 1 to 4 were transformed into 2 categories, 1 and 2, according to the following criteria: postoperatively, score 1 represented the patients who maintained the scoring of resonance at T1, and score 2 represented the appearance of worsening of hypernasality in at least one degree.

The following results were considered as risk factors for the appearance or worsening of hypernasality: scores 2 and 3 related to the length (regular and short), mobility (regular and poor), and insertion of the palate (middle and anterior), values related to advancement of greater magnitude (>7 mm), and values related to the ratio between nasopharyngeal depth and palatal length greater than 0.70.

The hypernasality scores were compared at pre- and postoperative moments by the McNemar test. The comparison between groups according to the change or not in speech resonance after surgery was performed by the Mann-Whitney *U* test for categorical variables and the Student *t* test for continuous variables.

The association between each categorical variable (palatal length, mobility of soft palate, and levator veli palatini insertion) and hypernasality (appearance or worsening) was evaluated by univariate analysis, using the $\chi^2$ test. If the necessary conditions for the analysis were not observed, the Fisher exact test was applied. The correlation between each numerical variable (extent of MA and ratio between nasopharyngeal depth and palatal length) and hypernasality was evaluated by the Spearman correlation test. Then, the study analyzed which variables were considered explanatory in the multivariate analysis model—logistic regression ($P < .10$), considering the morphological and functional variables of the palate, MA, and the interaction between them. Values of $P < .05$ were accepted as significant.

## Results

### *Analysis of Hypernasality*

At T1, 51 (98%) patients presented normal speech resonance and 1 (2%) presented mild hypernasality. At T2, 21% (11/52) of patients experienced a worsening of resonance, while 79% (41/52) did not experience any change in resonance between time points. Statistically significant difference was observed between T1 and T2 ($P = .001$). Based on these results, the patients were divided into 2 groups: absence of hypernasality at both time points (G1) and appearance or worsening of hypernasality at T2 following surgery (G2).

### *Analysis of Morphological and Functional Aspects of the Palate*

*Palatal length.* Four (10%) patients in G1 presented with a long palate, 21 (51%) regular, and 16 (39%) short. In G2, 6 (54.5%) had regular palate and 5 (45.5%) had a short palate. However, there were no significant differences between groups ($P = .513$).

*Mobility of the levator veli palatini muscle.* Eighteen (43.9%) patients in G1 presented good mobility, 20 (48.8%) regular, and 3 (7.3%) with poor mobility. In G2, 1 (9%) individual presented good mobility, 7 (64%) regular, and 3 (27%) poor. A statistically significant difference was observed between groups ($P = .015$).

*Insertion of the levator veli palatini muscle.* In G1, 8 (19.5%) patients presented posterior insertion in the palate, 20 (48.8%) middle, and 13 (31.7%) anterior. In G2, 3 (27.3%) patients presented posterior insertion, 3 (27.3%) middle, and 5 (45.4%) anterior. There was no significant difference between groups ($P = .763$).

The result of scorings of morphological and functional aspects of the palate for groups G1 and G2 is presented in Table 3.

### *Analysis of Extent of MA and Ratio Between Nasopharyngeal Depth and Palatal Length*

**Extent of total *MA*.** Only 3 patients in G1 had an MA of greater magnitude (>7 mm). The measurements performed in patients in G1 ranged from 1.2 to 8.7 mm. In G2, the variation ranged from 1.6 to 5.8 mm, without significant differences between groups ($P = .154$).

*Ratio between nasopharyngeal depth and palatal length.* Only 3 patients in G1 presented with ratio values between nasopharyngeal depth and palatal length up to 0.70. The other patients presented values greater than 0.70. The ratio between objective measurements of nasopharyngeal depth and palatal length varied from 0.66 to 1.29 in G1 and 0.72 to 1.33 in G2, without significant difference between groups ($P = .431$).

### Univariate Analysis: Association Between Variables and Hypernasality After Surgical MA

Significant association was observed between the appearance of hypernasality and mobility of the levator veli palatini muscle ($P = .041$). There was no significant association between speech symptoms and the following aspects: palatal length ($P = .774$), insertion of levator veli palatini muscle ($P = .462$), extent of MA ($P = .190$), and ratio between depth and palatal length ($P = .507$). These results demonstrated that the occurrence of hypernasality is most likely related to the regular and poor mobility of the palate. The risk of appearance or worsening of hypernasality is also increased with the increase in the score of mobility of the palate (from 1 to 3).

### Multivariate Analysis by Binary Logistic Regression

Only the mobility of the palate influenced the appearance of hypernasality after surgical MA, confirming the results of the univariate analysis, and the regular mobility was considered the situation of greater risk for velopharyngeal dysfunction ($P = .010$). Data also revealed that the chances of appearance of speech symptoms after surgery were 98% lower for the group presenting good mobility of the palate before surgery. The effect of surgical MA expected for a population with similar characteristics as the present study is between 61% and 100%. The reliability of the logistic regression model was assessed by the Hosmer and Lemeshow test, without significant difference between the adjustment of data ($P = .322$), indicating that the model is reliable. After adjustment of the model, 79% of cases were correctly identified as success or failure by the binary logistic regression.

## Discussion

This study demonstrated, by auditory perceptual speech assessment, 11 of the 51 patients with normal speech resonance before surgical MA presented with hypernasality after surgery. Only one individual presenting mild hypernasality after surgery maintained this condition after the advancement.

Prior studies have also demonstrated that patients with normal resonance before orthognathic surgery may have impaired speech after this procedure (Janulewicz et al., 2004; Chua et al., 2010; Pereira et al., 2013b). Different from these results, Kim et al. (2012) investigated the impact of surgical MA between a group of 8 patients with cleft palate without hypernasality and a group of 9 patients without clefts, observing no change in resonance after surgery in each group and between them. The authors suggested that patients with cleft and without velopharyngeal dysfunction before orthognathic surgery did not present greater risk of worsening of velopharyngeal function compared to patients without clefts. The difference between these findings and the present study may be justified by the visible discrepancy between the number of participants with cleft palate in each investigation, that is, 52 in the present study and 8 in the comparison study (Kim et al., 2012).

Using a similar methodology as the present study, Chua et al. (2010) identified, in a prospective study, the appearance of hypernasality in 4 (36%) of 11 patients, 17 months after surgical MA. These authors also observed no correlation between the speech results and extent of MA, mainly because even patients with an advancement of small magnitude, such as 4 mm, presented deterioration of their velopharyngeal function.

These results corroborate the present findings, which revealed a mean extent of MA of 4.4 mm (variation 1.2-8.7 mm) for the group without speech resonance after surgery (G1) and 3.9 mm (variation 1.6-5.8 mm) for the group with hypernasality after MA (G2), with no statistical correlation between the extent of MA and the presence of hypernasality after surgery.

Other investigators, aiming to verify the factors related to worsening of the velopharyngeal function after MA, also investigated the influence of the extent of advancement on the speech outcomes (Janulewicz et al., 2004; Phillips et al., 2005; Chanchareonsook et al., 2007; McComb et al., 2011; Kudo et al., 2014). The horizontal surgical movements reported in these studies varied between 0.78 and 17 mm. The authors unanimously concluded that the extent of maxillary movement, individually, did not present correlation with the harmful speech outcomes caused by the surgical procedure. Chanchareonsook et al. (2007), for example, observed changes in speech resonance in one patient with MA of 0.78 mm, while Phillips et al. (2005) observed normal resonance, before and after surgery, in an individual whose horizontal movement of the maxilla was much greater, namely 10.9 mm.

The observation that the population without cleft do not present worsening of velopharyngeal function after orthognathic surgery (Kim et al., 2012; Pereira et al., 2013b; Kudo et al., 2014) leads to the suspicion that changes in palatal morphology and function are the predisposing factors to the appearance or worsening of hypernasality after surgery.

Within this context, investigators have indicated, as risk factors, the changes in nasopharyngeal depth, palatal length, and ratio between these measurements comparing the pre- and postoperative periods. Therefore, it is assumed that these factors might indicate, early in the preoperative evaluation, the risk of alteration in resonance after surgery (Schendel et al., 1979; Heliövaara et al., 2002; Kudo et al., 2014; Wu et al., 2015).

A seminal paper by Subtelny (1957) presented the palatal and nasopharyngeal measurements obtained by cephalometric analysis from 30 patients without cleft, aged 3 months up to

18 years. Subtelny (1957) demonstrated that the mean percentage of the ratio between nasopharyngeal depth and palatal length ( depth:length ratio) ranged from 60% to 70%, suggesting that values above these would indicate an unfavorable relationship for velopharyngeal closure. After this proposal, studies involving patients with cleft palate began to use quantitative measurements of structures of the velopharyngeal spaces, reinforcing the importance of these measurements for the interpretation of clinical results (Satoh et al., 2002; Lu et al., 2006; Silva et al., 2017).

In this study, the palatal length was evaluated subjectively, by perceptual judgment of the examiner in routine clinical attendances; and objectively, representing the real length of this structure, measured in millimeters. The nasopharyngeal depth was evaluated only objectively. These 2 quantitative measurements were obtained only to achieve the ratio between them, since this interaction indicates good or poor functioning of the velopharyngeal mechanism (Subtelny, 1957).

Therefore, the mean product resulting from depth:length ratio was 0.96, ranging between 0.66 and 1.29 for G1, and 1.01, varying between 0.72 and 1.33 for G2. It should be highlighted that only 3 patients in G1 presented ratio values between 0.60 and 0.70, while the other 38 patients presented values between 0.76 and 1.29, indicating greater risk for the occurrence of hypernasality. No difference was observed between groups, and there was no correlation between DLR and the presence of hypernasality postoperatively.

Lu et al. (2006) found mean values of depth:length ratio of 1.08 for patients with repaired cleft palate and velopharyngeal insufficiency, 0.80 for adults with velopharyngeal competence, and 0.85 for adult patients without cleft, inferring that higher DLR values than those found by Subtelny (1957) may also be observed in patients with good velopharyngeal closure. The authors also mentioned that one individual with velopharyngeal dysfunction participating in the study presented depth:length ratio value of 0.69. This difference between studies indicates that other factors, besides the palatal length, may contribute to the velopharyngeal closure of patients with cleft palate, such as denervation of the levator veli palatini muscle or participation of the lateral and posterior pharyngeal walls.

Kummer et al. (1989) investigated the effects of Le Fort I osteotomy with MA on the articulation, speech, and velopharyngeal function and observed evidences which the authors called “compensatory changes” in velopharyngeal structures due to surgery. By videofluoroscopy examination and using scores to classify the variables analyzed, the authors observed difference of one point in the scale for scoring of palatal length and movement of lateral walls during speech after surgery. The results demonstrated that 33% of patients presenting palatal length scored as short before surgery exhibited regular length after the procedure.

Most diagnostic and therapeutic approaches related to the velopharyngeal mechanism are strictly related to basic anatomy. In the present study, according to the perceptual judgment of the palate at rest before surgery, it was observed that, among the 52 patients, only 4 (8%) presented with a long palate, while 27 (52%) exhibited a regular length palate, and 21 (40%) with a short palate, without significant difference between groups. Consequently, significant association between this variable and postoperative hypernasality was not observed. Thus, the high number of patients with a regular and short palate and similar distribution between groups suggests that this variable is not a risk factor for the appearance of speech symptoms after surgical MA.

Concerning the mobility of the palate, significant difference was observed between groups G1 and G2. The mobility was scored as good in 18 (43.9%) patients in G1, and only 1 (9%) individual in G2 presented good mobility of the palate. Association of this variable with the presence of hypernasality after surgical MA was also observed.

Nohara et al. (2006) used electromyography of the levator veli palatini muscle in 4 patients with cleft palate without hypernasality following MA to determine whether there are predictors to the deterioration of velopharyngeal function post-surgically. During speech production, before MA, 2 patients presented amplitude of activity of the levator muscle lower than 60% of its total contraction capacity (compatible with results observed in the population without cleft), while the other 2 patients presented amplitude above 60% (similar to those found in a population with velopharyngeal dysfunction). After surgery, only patients with higher percentage of amplitude of muscle activity presented hypernasality. The authors concluded that worsening of the velopharyngeal function was related to a reduction in the reservoir capacity of contraction of the levator veli palatini muscle, with consequent reduction in the complementary muscle activity required to maintain the adequate velopharyngeal closure during speech after the surgical procedure.

Considering the presence of energetic reservoir capacity of the muscle, it is assumed that patients in the present study with good mobility of the palate, despite the anterior traction of the palate, presented good reservoir capacity of muscle contraction compared to those with regular or poor mobility and thus achieved complete velopharyngeal closure. This may explain the reduced risk (2%) of patients with good mobility of the palate to present hypernasality after anterior maxillary repositioning, as evidenced by the statistical analysis of results.

Other explanation for the speech outcomes found in the present study may be related to the capacity of elongation of the palatal muscles during the elevation movement in speech. The process known as “velar elasticity” refers to elongation of the palate during the elevation movement. In patients following MA, this elongation is considered a compensatory behavior to maintain the velopharyngeal closure even after anterior maxillary displacement (Kummer et al., 1989; Kummer, 2014; Wu et al., 2015). This may explain why some patients in this study, who presented regular or even poor mobility of the palate before surgery, exhibited normal resonance after MA.

Regarding the insertion of the levator veli palatini muscle, no significant difference was observed between groups G1 and G2. Similarly, no association was observed between this variable and the presence of hypernasality after surgical MA. Even though anterior insertion of the palatal muscles is observed in many patients with velopharyngeal dysfunction (Nakamura et al., 2003; Perry and Kuehn, 2009; Rocha, 2010; Yamashita et al., 2012), all patients in the present study exhibiting this condition (21/52) had hypernasality scored as absent before surgery, and few (5/21) began to present speech symptoms after surgical MA.

The deficient growth of the midface may explain these findings, since the maxillary atresia causes narrowing of the nasopharynx (Tarawneh et al., 2018), favoring the correct velopharyngeal functioning. Thus, even in cases with anterior insertion of the levator veli palatini muscles, the complete velopharyngeal closure may be achieved without great effort of the musculature. Additionally, the good mobility of the palate and presence of movement of pharyngeal walls during speech may favor the adequate velopharyngeal function in these cases. However, caution should be taken regarding this measure because direct muscle imaging was not used to confirm if visual inspection of the muscle location was consistent with actual muscle position. Future studies using magnetic resonance imaging may prove to be a resourceful tool to examine this specific observation with more clarity.

It is known that surgeries performed in the present patients did not involve only horizontal movements. This may be considered a limitation of this study, since the vertical movements and maxillary rotation performed were not controlled and should be considered in future studies to investigate their influence on speech.

## Conclusion

The present results concluded that, among the morphological and functional conditions of the velopharyngeal region analyzed, the mobility of the levator veli palatini muscle was considered a risk factor for worsening of the velopharyngeal function, caused by the appearance of hypernasality after surgical MA in a population with cleft palate. Additionally, this study demonstrated that the other factors (palatal length, insertion of levator veli palatini muscle, ratio between nasopharyngeal depth, and palatal length) did not represent risk to worsening of the velopharyngeal function, regardless of the extent of surgical MA.

### Acknowledgments

To the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES—Ministry of Education of Brazil) for the financial assistance to the implementation of this study.

### Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

### Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES—Ministry of Education of Brazil), process number 88881.131548/2016-01.

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