Nasal Septal Anatomy in Skeletally Mature Patients With Cleft Lip and Palate

Jonathan P. Massie, BS; Christopher M. Runyan, MD, PhD; Marleigh J. Stern, BA; Michael Alperovich, MD; Scott M. Rickert, MD; Pradip R. Shetye, DDS; David A. Staffenberg, MD; Roberto L. Flores, MD

IMPORTANCE Septal deviation commonly occurs in patients with cleft lip and palate (CLP); however, the contribution of the cartilaginous and bony septum to airway obstruction in skeletally mature patients is poorly understood.

OBJECTIVES To describe the internal nasal airway anatomy of skeletally mature patients with CLP and to determine the contributors to airway obstruction.

DESIGN, SETTING, AND PARTICIPANTS This single-center retrospective review included patients undergoing cone-beam computed tomography (CBCT) from November 1, 2011, to July 6, 2015, at the cleft lip and palate division of a major academic tertiary referral center. Patients met inclusion criteria for the study if they were at least 15 years old at the time of CBCT, and images were used only if they were obtained before Le Fort I osteotomy and/or formal septorhinoplasty. Twenty-four skeletally mature patients with CLP and 16 age-matched control individuals were identified for the study.

MAIN OUTCOMES AND MEASURES Septal deviation and airway stenosis were measured in the following 3 coronal sections: at the cartilaginous septum (anterior nasal spine), bony septum (posterior nasal spine), and midpoint between the anterior and posterior nasal spine. The perpendicular plate of the ethmoid bone and vomer displacement were measured as angles from the vertical plane at the coronal section of maximal septal deviation. The site of maximal septal deviation was identified.

RESULTS Among the 40 study participants, 26 were male. The mean (SD) age was 21 (5) and 23 (6) years for patients with CLP and controls, respectively. Septal deviation in patients with CLP was significantly worse than that of controls at the anterior nasal spine (2.1 [0.5] vs 0.8 [0.2] mm; P < .05) and posterior nasal spine (2.9 [0.5] vs 1.0 [0.3] mm; P < .01) and most severe at the midpoint (mean [SD], 4.4 [0.6] vs 2.1 [0.3] mm; P < .01). The point of maximal septal deviation occurred in the bony posterior half of the nasal airway in 27 of 40 patients (68%). The CLP bony angular deviation from the vertical plane was significant in the CLP group compared with the control group (perpendicular plate of the ethmoid bone, 14° [2°] vs 8° [1°]; vomer, 34° [5°] vs 13° [2°]; P < .05 for both), and vomer deviation was significantly associated with anterior nasal airway stenosis (r = −0.61; P < .01).

CONCLUSIONS AND RELEVANCE Skeletally mature patients with CLP have significant septal deviation involving bone and cartilage. Resection of the bony and cartilaginous septum should be considered at the time of definitive cleft rhinoplasty.

LEVEL OF EVIDENCE NA.
The nasal septum is one of the cardinal skeletal support systems of the nose and has previously been shown to be deviated in patients with cleft lip and palate (CLP). In addition, the nasal airflow is severely affected in patients with CLP, with nasal airflow resistances 20% to 30% higher than those in the general population. A variety of factors have been shown to contribute to airway obstruction, including septal deformities, atresia of the nostrils, and turbinate hypertrophy. Whereas the latter issues are often addressed in the course of primary or definitive nasal repair for patients with CLP, optimal management of the septum in correcting nasal obstructive symptoms remains poorly defined.

Traditionally, nasal bony manipulation is avoided until skeletal maturity is reached to avoid growth deficiencies. However, even during definitive rhinoplasty at adolescence or adulthood, the main focus is the nasal cartilage and visible bony structures, with little consensus as to the surgical management of the bony septum. This lack of consensus can be attributed to the poor characterization of nasal septum anatomy in skeletal mature patients with CLP in the current literature. Before treatment guidelines can be established, a better understanding of the nasal septal anatomy in skeletally mature patients with CLP is needed.

The advent of cone-beam computed tomography (CBCT) allows the acquisition of high-quality 3-dimensional images of facial structures with reduced radiation doses compared with multissection CT. Routine acquisition of CBCT scans by our cleft lip and palate team as a component of dental evaluation enabled us to obtain CT scans of a sizeable population of skeletally mature patients with CLP and age-matched control patients. With these scans, we performed a comprehensive analysis of the anatomy of the nasal airway in skeletally mature patients with CLP.

Methods

Patient Selection and Study Sample
This single-center retrospective review considered all skeletally mature patients with CLP who underwent CBCT scanning from November 1, 2011, to July 6, 2015, at the Department of Plastic Surgery, New York University Langone Medical Center, and who were at least 15 years old at the time of CBCT. Patients were excluded from the study if they had a cleft palate only. The CBCT scans were used only if they were obtained before Le Fort I osteotomy and/or formal septorhinoplasty. Age-matched controls were identified as patients without CLP who underwent CBCT evaluation for orthognathic surgery consultation or after facial trauma. No controls were included for whom nasal trauma was the primary reason for the CBCT scan. Institutional review board approval was obtained from New York University before the start of this study. The need for informed consent was waived by the institutional review board.

CBCT Analysis
The CBCT scans were analyzed using Dolphin Imaging Software (Patterson Dental) by two of us (J.P.M. and C.M.R.). A single rater (J.P.M.) repeated the CBCT analysis. Before measurement, CBCT scans were oriented in the horizontal plane using the infraorbital rims as a reference and in the vertical plane using the zygomatic arch to the infraorbital rim. The measurements described below were performed on all CBCT scans.

Septal Deviation
Septal deviation was measured in coronal sections at the level of the anterior nasal spine (ANS), the posterior nasal spine (PNS), the ANS-PNS midpoint, and the point of maximal septal deviation. Septal deviation was calculated as the mean of the distance of the right mucosal septum and left mucosal septum from the midline (Figure IA).

Airway Stenosis
Airway stenosis was similarly measured in coronal sections at the ANS, PNS, and ANS-PNS midpoint, and maximal septal deviation. Stenosis was measured as the smallest linear distance between the mucosal nasal septum and adjacent turbinate or lateral nasal wall (Figure IB).

Bony Angle Deviation
Bony angular deviation from the vertical plane was measured at the maximal septal deviation for the perpendicular plane of the ethmoid bone (PPE) and vomer (Figure IC and D). The PPE angle from the vertical plane was defined from the point of maximal septal deviation to the skull base, and the vomer angle from the vertical plane was defined from the point of maximal septal deviation to the nasal floor. In cases for which the maximal septal deviation did not include bony septum, angular measurements were not obtained.

Characterizing the Point of Maximal Septal Deviation
The point of maximal septal deviation was identified for all patients (eFigure in the Supplement), and we noted whether this point occurred in the cartilaginous or bony septum. In addition, the 3-dimensional location of the maximal septal deviation was recorded for the sagittal axis (right vs left of midline), axial axis (superior vs inferior to the midpoint from skull base to nasal floor), and coronal axis (anterior vs posterior to the midpoint from the ANS to PNS).

Key Points

**Question** How does the cartilaginous and bony septum contribute to airway obstruction in skeletally mature patients with cleft lip and palate (CLP)?

**Findings** In this review of 24 skeletally mature patients with CLP, septal deviation was significantly worse than that of controls in all anatomical planes studied, and bony septum angular deviation was significantly associated with anterior airway stenosis. The point of maximal septal deviation occurred in the bony posterior half of the nasal airway in most patients.

**Meaning** Resection of the bony and cartilaginous septum should be performed at the time of definitive cleft rhinoplasty for relief of airway obstruction in patients with CLP.
Statistical Analysis
All data were analyzed using Prism software (version 6.07; GraphPad) or SPSS (version 23; IBM). Pairwise data were analyzed using the unpaired, 2-tailed t test. Multivariable linear regression was performed between the independent variables ANS septal deviation, PNS septal deviation, ANS-PNS midpoint septal deviation, PPE angle, and vomer angle and the dependent variables of ANS, ANS-PNS midpoint, and PNS airway stenosis in an effort to characterize determinants of airway obstruction. Intrarater and interrater reliabilities were assessed using the Pearson product moment correlation coefficient. Statistical significance was held at P < .05. Unless otherwise indicated, data are expressed as mean (SD).

Results

Patient Examination
Twenty-four patients with CLP (19 male and 5 female) and 16 control patients (7 male and 9 female) were identified for inclusion in the study and were well matched with a mean (SD) age of 21 (5) and 23 (6) years at the time of CBCT, respectively. Ages ranged from 15 to 33 years at the time of CBCT scan for patients with CLP and from 15 to 37 years for controls. Within the CLP group, 11 patients had unilateral CLP and 13 patients had bilateral CLP. Controls underwent CBCT scans for orthognathic evaluation or after facial trauma. Intrarater reliability for 310 repeated measurements as calculated by Pearson product moment correlation was r = 0.96 (P < .001); interrater reliability for 80 repeated measurements, r = 0.92 (P < .001).

Severity of Septal Deviation
Septal deviation measured at the ANS, PNS, and ANS-PNS midpoint was significantly worse in patients with CLP compared with controls (P < .05 for all) (Figure 2A). Moreover, septal deviation within patients with CLP tended to be most severe near the midpoint of the nasal airway (4.4 [0.6] mm), which was significantly more deviated than the anterior airway (2.1 [0.5] mm; P < .01) (Figure 2A). Midpoint septal deviation represented 79% of the septal deviation observed at the point of maximal septal deviation (5.6 [0.7] mm). Controls also exhibited a similar pattern of septal deviation, with the midpoint septal deviation (2.1 [0.3] mm) accounting for 78% of maximal septal deviation (27 [0.3] mm) (Figure 2A). This finding suggests that the middle to posterior nasal septum is inherently more susceptible to deviation, and this association is significantly more apparent in patients with CLP. Significant differences in septal deviation were not observed between patients with unilateral vs bilateral CLP (Figure 2A).

Airway Stenosis
Patients with CLP had a significant degree of airway stenosis at the ANS, PNS, and their midpoint compared with controls (P < .05 for all) (Figure 2B). In addition, in the CLP group, stenosis was critically severe at the midpoint (0.4 [0.1] mm), which was significantly more stenotic than the ANS (1.4 [0.2] mm; P < .001) and PNS (1.2 [0.2] mm; P < .001) (Figure 2B). Stenosis at the midpoint was about 0.1 mm smaller than the stenosis observed at the point of maximal septal deviation (0.5 [0.2] mm). Significant differences were not observed between patients with unilateral vs bilateral CLP (Figure 2B).
Vomer Deviation and Nasal Airway Patency

The vomer was significantly deviated from the vertical plane in patients with CLP (34° [5°]) vs controls (13° [2°]; P < .05) (Figure 2C). A significant difference was also observed in the angle of the PPE (14° [2°]) from the vertical plane when compared with controls (8° [1°]; P < .01) (Figure 2C). In addition, no differences were observed in the PPE or vomer angle between patients with unilateral vs bilateral CLP (Figure 2C). In 3 patients, bony angular measurements could not be obtained because bone was not present at the point of maximal septal deviation. In 2 patients, the PPE was visible, but the vomer was not.

In multivariable linear regression models, the degree of vomer displacement from the vertical plane was the only variable that correlated with any degree of nasal airway stenosis (Figure 2C). Allothervariablesstudied, including septal deviation at the ANS, PNS, and their midpoint and the PPE angle, did not significantly correlate to ANS stenosis (P > .05). Furthermore, multivariable models could not be built for stenosis outcomes at the ANS-PNS midpoint, PNS, and maximal septal deviation because we found no degree of correlation with any of the input variables (septal deviation of the ANS, PNS, or their midpoint, maximal septal deviation, PPE angle, and vomer angle). As visualized by a univariate plot, the degree of vomer deviation was significantly associated with anterior nasal airway stenosis (r = −0.61; P < .01) (Figure 3).

Maximal Septal Deviation

The point of maximal septal deviation was most often located in the inferior portion of the nasal airway in patients with CLP (19 [79%]) and controls (10 [63%]) and was most often located in the posterior airway in both groups (CLP, 17 [71%]; controls, 11 [69%]) (Table). In 37 of the total 40 patients examined, the point of maximal septal deviation occurred within the bony septum (Figure 2C). Within the unilateral CLP group, 7 patients demonstrated maximal septal deviation that was ipsilateral to their...
cleft side, whereas 4 exhibited maximal septal deviation on the opposite side of their cleft.

Discussion

We present a CBCT analysis of nasal septal morphologic features in skeletally mature patients with CLP. The mean patient age was 21 years, whereas nasal bony growth is considered to be complete around 11 to 12 years of age in girls and 13 to 14 years of age in boys.17 The oldest cohort to be examined before this study, to our knowledge, was by Jiang et al,7 with a mean age of 16 years; however, their study group included a mixed-age population with patients who had not yet achieved skeletal maturity (as young as 7 years). In addition, their study was limited to analysis of nasal anatomy in a single anatomical plane, for which few conclusions can be drawn.

Our study takes advantage of 3-dimensional CBCT scans to obtain a comprehensive assessment of nasal anatomy. All scans were obtained for orthodontic planning, and no scans were obtained solely for the purpose of this study. Compared with the traditional 64-section CT scans, CBCT scans reduce the effective radiation dose by more than 6-fold.16 Although a previous study by Friel et al8 looked at nasal anatomy in various anatomical planes at the time of mixed dentition using CBCT, their study was limited in that control scans were obtained by a different imaging modality (multisection CT). Also their study used a younger population, for which conclusions about nasal anatomy at skeletal maturity cannot be drawn.

Our results underscore the importance of the bony septum to overall nasal architecture and as a potential link to airway obstruction. Septal deviation is more severe from the ANS-PNS midpoint to the PNS, with more than 70% of patients with CLP demonstrating maximal septal deviation in the posterior half of their nasal airway. Previous studies have shown that this area (from the midpoint to the PNS) consists of 96% bone.8 Therefore, septal deviation was most severe in areas related to the bony septum. Further highlighting the importance of the bony septum in nasal anatomy, vomer deviation was significantly associated with anterior nasal airway stenosis, suggesting that bony architecture can affect airway patency. We observed no correlation between the cartilaginous septal deviation at the ANS and stenosis at any anatomical point throughout the airway. We also observed that airway stenosis was severe at the transition zone from the cartilaginous to bony septum (near the midpoint), indicating that this junction is particularly susceptible to obstruction and warrants attention superiorly at the level of the cartilage and inferiorly at the level of the vomer.

To understand the implications of our septal data on airway obstruction requires a basic understanding of airflow dynamics. Airway obstruction comes from 2 interrelated causes: physical airway stenosis and turbulent airflow.18 Nasal anatomy allows for a delicate balance between laminar and turbulent airflow. Under laminar flow, the force needed to achieve airflow is proportional to the diameter of the airway opening. Turbulent airflow, on the other hand, requires a force proportional to the diameter squared, consequently needing a significantly greater force to produce the same airflow when compared with laminar flow.19 In the proper circumstances,
turbulent airflow can help increase airway resistance, resulting in prolonged nasal mucosal contact of inspired air to allow for humidification and warming. However, pathologic increases in turbulent airflow as caused by septal deviation can result in resistances that further exacerbate airway obstruction. Thus, a deviated septum not only causes physical stenosis, but disturbs airflow exponentially by creating a turbulent environment.

Adult cleft rhinoplasty commonly highlights cartilaginous septoplasty for cosmetic and reconstructive purposes, but our results suggest that the bony septum merits further attention. Based on our anatomical findings, patients with CLP who demonstrate airway obstruction secondary to septal deviation should undergo submucous resection of the cartilaginous septum. After this procedure, the remaining bony septum, including the vomer and PPE, should be carefully inspected for any residual obstruction by the bony septum. Osteophytes and other bony deviations causing airway stenosis may then be removed directly using an osteotome or nasal forceps (Takahashi; KLS Martin). Bony resection will require thorough dissection of the nasal mucosa and may require resection of bone as far posterior as the sphenoid. This bony resection increases the risk for mucosal tears, postoperative bleeding, and in rare cases cerebrospinal fluid leak and therefore should be performed with a thorough understanding of intranasal anatomy and the techniques of submucous resection. Nevertheless, we recommend that bony septal deviation must be addressed in this patient population to relieve obstructive symptoms and achieve adequate nasal symmetry.

Hypertrophic inferior or middle turbinates may further contribute to nasal airway obstruction. Our study indirectly evaluates the involvement of turbinate hypertrophy, because our stenosis measurements occurred at the areas of greatest narrowing between the septum and adjacent turbinates. Pre-surgical workup of definitive cleft rhinoplasty should include consideration of medical and surgical treatment of turbinate hypertrophy, as appropriate.20 Our study has several limitations. We report a small sample size with a mix of patients with unilateral and bilateral CLP. Despite this limitation, we have found statistically significant differences in septal deviation, nasal airway stenosis, and PPE and vomer angles in patients with CLP compared with controls. Therefore, one would expect a larger sample size would only strengthen the existing significant differences observed herein. Patients underwent CBCT analysis as part of their orthodontic evaluation for possible orthognathic surgery, which creates a potential selection bias to more severely affected patients with a cleft. Therefore the results of this study may not be applicable to patients with CLP and no midface hypoplasia. In addition, the anatomy of the turbinates is not directly reported in our study; however, this topic should be the subject of future research because turbinate hypertrophy is well appreciated in this patient population. Furthermore, this study is anatomical and not functional. Although this differentiation presents a limitation, anatomical studies may still aid surgical advancement by informing which physiologic studies warrant future attention. Our results, along with several previous studies,8,20 suggest that septal contribution to airway patency is one such topic. We hope these findings will spark interest in future studies that investigate the functional contribution of the septum to help confirm our findings.

Conclusions

Skeletally mature patients with CLP demonstrate nasal septal deviation involving the cartilaginous and bony septum. Deviation of the bony septum is more severe than cartilaginous deviation, and bony deviation correlates with airway stenosis. Therefore, resection of the bony and cartilaginous septum should be performed at the time of definitive cleft rhinoplasty to relieve airway obstruction and achieve nasal symmetry.


