Original Article

Three-dimensional nasal septum and maxillary changes following rapid maxillary expansion in patients with cleft lip and palate: *A case-series analysis*

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ABSTRACT

Objectives: To determine the three-dimensional changes of the nasal septum (NS), alveolar width, alveolar cleft volume, and maxillary basal bone following rapid maxillary expansion (RME) in consecutive patients with unilateral cleft lip and palate (UCLP).

Materials and Methods: A retrospective investigation was conducted based on the analysis of cone-beam computed tomography (CBCT) data of 40 consecutive patients with UCLP (mean age 11.1 ± 2.2 years). Scans were acquired prior to RME (T0) and after removal of the expander (T1) before graft surgery. A three-dimensional analysis of the effects of RME on the nasal septum, alveolar width, alveolar cleft volume, and maxillary basal bone was performed.

Results: No changes in the NS deviation were observed following RME ($P > .05$). Significant increases of the alveolar transverse dimension were found in the anterior (14.2%; $P < .001$) and posterior (7.7%; $P < .001$) regions as well as in the volume of the alveolar cleft (19.6%; $P < .001$). No changes in the basal bone dimensions and morphology were observed ($P > .05$).

Conclusions: Following RME, no changes were observed in the NS and maxillary basal bones of patients with UCLP despite the significant gain in the anterior and posterior alveolar width and the increase of the alveolar cleft defect. Clinicians should be aware that maxillary changes following RME in patients with UCLP are restricted to the dentoalveolar region. (*Angle Orthod.* 2020;90:672–679.)

KEY WORDS: Nasal septum; Cleft palate; Cleft lip; Palatal expansion technique; Tomography

INTRODUCTION

One of the most frequent craniofacial anomalies is cleft lip and palate (CLP), affecting approximately 1 in every 700 live births. Cleft lip and palate compromises the quality of life of more than 7 million people worldwide[1] and leads to functional, esthetic, and psychological disturbances.[2] During the first years of life, patients with cleft typically undergo lip and alveolar repair surgeries that create scar tissue that commonly causes a transverse maxillary deficiency, especially in the anterior region.[3]

Rapid maxillary expansion (RME) has been the gold-standard procedure to improve the maxillary transverse dimension in patients with clefts, which is

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Table 1. Changes of the Nasal Septum, Alveolar Width, and Alveolar Cleft Volume from T0 to T1[a]

	T0		T1						
Measures	Mean	SD	Mean	SD	T1–T0	% Change	*P* Value	Effect Size	Power
MLA	14.3	4.8	14.2	5.0	−0.1	<1	.440	0.40	0.69
PBA	19.3	6.6	19.5	6.6	+0.2	<1	.168	0.30	0.46
DMDP	5.9	2.0	5.8	2.1	−0.1	<1	.070	0.47	0.83
AWA	26.8	2.51	30.6	3.27	+3.8	14.2	<.001	0.30	0.46
AWP	40.1	2.88	43.2	2.69	+3.1	7.7	<.001	0.34	0.55
ACV	572.37	252.28	684.82	295.80	+112.44	19.6	<.001	0.46	0.81

[a] MLA indicates midline angle; PBA, palatal border angle; DMDP, distance of the most-deviated point of the nasal septum to the facial midline; AWA, alveolar width anterior; AWP, alveolar width posterior; ACV, alveolar cleft volume; SD, standard deviation.

an essential condition for alveolar bone grafting.[4] The expansion forces, which aim to separate the two maxillary halves, are not only restricted to the intermaxillary sutures but also distributed to other structures, such as the zygomatic and sphenoid bones and the nasal septum (NS).[5] It has been reported that the heavy forces applied increase the maxillary alveolar width more than the maxillary basal width, supporting the idea that alveolar deformation might explain the majority of the transverse changes following RME.[6] It may also significantly widen the alveolar cleft defect, which in turn might compromise the success of the bone graft.[7] In addition, RME has a significant impact on the geometry and function of the nasal cavity, providing lateral displacement of the walls and facilitating flow through the upper airway.[8] These effects are very important to patients with clefts because they usually exhibit reduced upper airway dimensions, adenoid hypertrophy, sleep disorders, oral breathing, and a marked NS deviation. The NS deviation is one of the major causes of nasal obstruction in patients without clefts and often results in blocking of the nasolacrimal ducts, sinusitis, ear infections, and mouth breathing. However, NS deviation in patients with clefts commonly persists even after surgical repair of the cleft, which might lead to chronic obstruction of the air passage until septorhinoplasty can be performed between 14 and 18 years of age.[9]

The literature regarding the impact of RME on the NS is controversial. A previous study showed that there was a reduction in the NS deviation post-RME in patients without clefts.[10] Others have reported that there was no alteration in the NS after RME.[11,12] In addition, although the effects of RME on the upper airways[13] and on the UCLP[8,14] are well documented, there is a lack of studies in the literature that analyzed its effects on the nasal septum in UCLP patients, especially using cone-beam computed tomography (CBCT).

The aim of this study was to determine three-dimensional (3D) changes in the NS, alveolar width, alveolar cleft volume, and maxillary basal bone following RME in a series of consecutive UCLP patients.

MATERIALS AND METHODS

Participants, Eligibility Criteria, and Settings

This case-series study was written according to the PROCESS (Preferred Reporting Of CasE Series in Surgery) guidelines for the improvement of the quality of scientific reports.[15] It was based on the consultation of patients' orthodontic records from the Cleft Center of the Department of Orthodontics of the Pontifical Catholic University of Minas Gerais. As this was a retrospective study, a priori sample-size calculation was not performed. The calculated post hoc power is shown in Tables 1 and 2.

The study was approved by the Institutional Ethics Committee and registered at ClinicalTrials.gov (NCT03976609). All patients and/or their parents signed informed consents before treatment was initiated. The institution is an academic referral center for patients with clefts in a state with 21 million people. It is privately owned, but the resources for the treatment of craniofacial abnormalities come from public governmental funds. The sample comprised 40 UCLP (17 girls; 27 left-side and 13 right-side clefts), ages 8 to 14 years old (mean age of 11.1 $\pm$ 2.2 years).

The inclusion criteria were the following: (1) the presence of UCLP, (2) RME as an initial procedure of the orthodontic treatment, (3) absence of previous orthodontic treatment, and (4) CBCTs acquired at the beginning of treatment as part of the standard records for patients with craniofacial abnormalities (T0) and following expander removal in preparation for adequate bone grafting (T1). The exclusion criteria included (1) absent maxillary permanent first molars, (2) signs of active periodontal disease, and (3) the presence of any additional craniofacial disorders.

All patients were in the prepubertal or pubertal stage of maturation based on cervical vertebral maturation[16] assessed on reconstructed lateral cephalograms generated from the T0 CBCT.

Table 2. Changes of the Maxillary Basal Bone Measurements from T0 to T1[a]

Measures	Component	Mean	SD	*P* Value	Effect Size	Power
ANS	X	0.2	0.39	.588	2.56	1.0
	Y	0.1	0.28	.091	3.57	1.0
	Z	0.8	0.43	.416	2.32	1.0
	3D	0.8	0.46	.131	2.17	1.0
Zygomatic left	X	0.0	0.58	.532	1.72	1.0
	Y	0.3	0.46	.032	2.17	1.0
	Z	0.2	0.33	.198	3.03	1.0
	3D	0.3	0.43	.464	2.32	1.0
Zygomatic right	X	0.0	0.57	.678	1.75	1.0
	Y	0.3	0.52	.359	1.92	1.0
	Z	0.2	0.35	.09	2.85	1.0
	3D	0.4	0.43	.17	2.32	1.0
PF right	X	0.2	0.46	.642	2.17	1.0
	Y	0.0	0.33	.414	3.03	1.0
	Z	0.6	0.71	.804	1.40	1.0
	3D	0.4	0.5	.38	2.0	1.0
PF left	X	0.2	0.63	.245	1.58	1.0
	Y	0.2	0.52	.269	1.92	1.0
	Z	0.4	0.31	.17	3.22	1.0
	3D	0.5	0.53	.448	1.88	1.0
Palatal plane	X	−0.19	0.39	.318	2.56	1.0
	Y	0.65	0.76	.308	1.31	1.0
	Z	0.3	0.52	.126	1.92	1.0
Zygomatic plane	X	0.27	0.89	.389	1.12	1.0
	Y	−0.01	0.53	.43	1.88	1.0
	Z	−0.02	0.67	.522	1.49	1.0
PF plane	X	−2.23	2.98	.378	0.33	0.53
	Y	−0.17	0.98	.023	1.02	1.0
	Z	0.11	0.36	.184	2.77	1.0
PF/zygomatic plane right	X	1.74	2.45	.871	0.4	0.69
	Y	1.1	1.96	.834	0.51	0.88
	Z	−0.85	1.97	.359	0.5	0.87
PF/zygomatic plane left	X	1.05	2.14	.934	0.47	0.82
	Y	−0.5	1.53	.949	0.65	0.98
	Z	0.9	2.01	.923	0.49	0.85

[a] ANS indicates anterior nasal spine; PF, palatine foramen; SD, standard deviation.

Interventions

For the transverse adjustment of the constricted maxillary arch, patients used a Hyrax expander (Dentaurum, Ispringen, Germany) with bands cemented on the permanent first molars with fluoride-releasing cement (Ultra Band-Lok, Reliance, Itasca, Ill), and extension arms were applied to all teeth in the posterior region. The activation regimen was 2 turns/day until the tip of the lingual cusps of the maxillary teeth reached the tips of the buccal cusps of the mandibular teeth. Patients were followed up monthly during the 3-month retention period. After that time, the expander was removed and a postexpansion CBCT scan (T1) was immediately acquired for adequate secondary bone graft surgical planning. After the post RME CBCT scan (T1), a transpalatal bar was inserted as a retainer. Two assistant orthodontists treated all cases, ensuring quality and maintaining consistency among all cases.

Image Analysis

A senior radiology technician acquired all scans using an iCat machine (Imaging Sciences International, LLC, Hatfield, Pa) with a 40-second scan, a 23 × 17-cm field of view and a voxel size of 0.3 mm. Head orientation of the patients in the three planes of space, using the frontal, right lateral, and superior views, was performed as previously described.[17] Changes in the maxillary alveolar width and NS were analyzed with Dolphin Imaging software (11.7, Dolphin Imaging & Management Solutions, Chatsworth, Calif). Volume changes in the alveolar cleft were analyzed with ITK-SNAP (open-source software, www.itksnap.org). Basal bone changes were analyzed using ITK-SNAP and 3D SLICER (open-source software, www.slicer.org). A doctorate student with 8 years of training in orthodontics and previously calibrated with the methodology conducted the analyses.

Nasal Septum (NS) Measurements

The following measurements were performed to evaluate the NS, and the coronal planar view (two dimensional) used contained the apex of the deviated septum on the cleft side:

1. Midline angle (MLA)[18]: In the coronal view, this was the angle between the midsagittal plane (crista galli and center of the anterior contour of magnum foramen) and another line from the crista galli to the apex of the septal deviation (Figure 1A,B).
2. Distance of the most-deviated point of the NS to the midsagittal plane (DMDP): In the coronal view, this was the linear distance between the perpendicular line from the midsagittal plane to the most-deviated point of the NS (Figure 1A,B).
3. Palatal border angle (PBA): In the coronal view, this was the angle between a line drawn from the crista galli to the deepest point on the curvature of the palatal roof on the noncleft side, and a line from crista galli to the most-deviated point of the NS (Figure 1C,D).

Alveolar Cleft Volume (ACV)

Using the T0 and T1 scans oriented with the palatal plane parallel with the ground, the alveolar cleft upper limit (point A) and lower limit (prosthion, the point of the maxillary alveolar process that projected most anteriorly in the midline) were used for calculation of the ACV (Figure 2A). The alveolar cleft region was selected in all axial slices within the limits established and the volume was automatically calculated (ACV; Figure 2B).

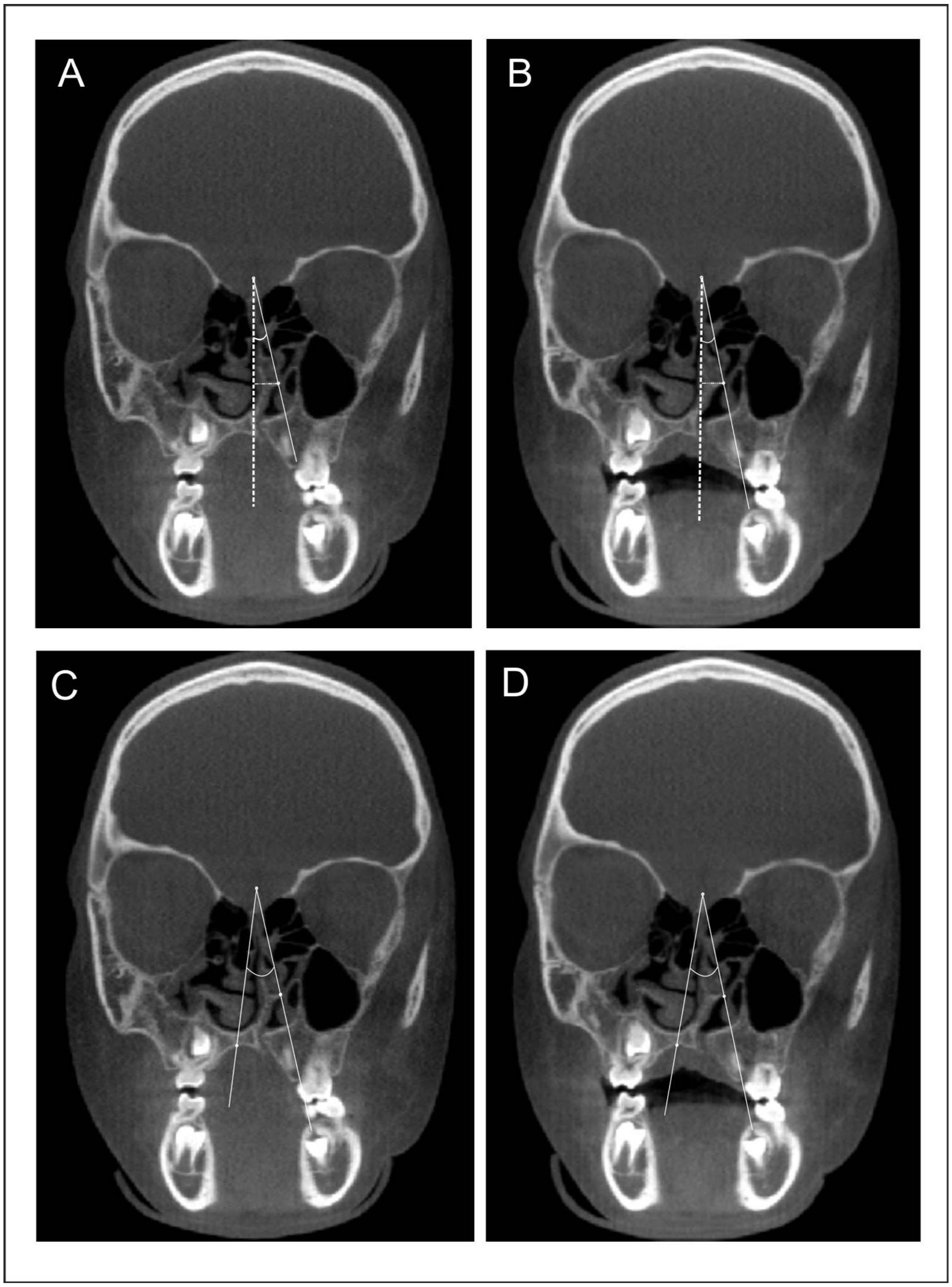

Figure 1. Linear and angular measurements of the displacement of the nasal septum in the coronal view. Left-side images (A,C) are pre-expansion. Right-side images (B,D) are post-expansion. (A,B) Illustration of the measurement of MLA and distance of the most-deviated point of the NS to the facial midline. (C,D) Illustration of the measurement of the palatal border angle. Dashed lines in A and B are the midsagittal plane.

Alveolar Width Anterior (AWA) and Alveolar Width Posterior (AWP) Measurements

The inter–first permanent molar distance was considered as the AWP. The distance between the first premolars or first primary molars was considered as the AWA (Figure 2C). The center of the palatal root canal at the level of the root furcation was used as the reference for the identification of the landmarks in the axial view.[19]

Maxillary Basal Bone (MBB)

The T1 scan was manually approximated to T0 (best fit) in the multiplanar views, and then a fully automated voxel-based registration was performed using the anterior cranial base as a reference.[17] Six specific landmarks were located simultaneously in the sagittal, coronal, and axial views (Figure 3). Each spherical landmark was 3 voxels in diameter. The landmarks were as follows: (1) anterior nasal spine (ANS), (2)

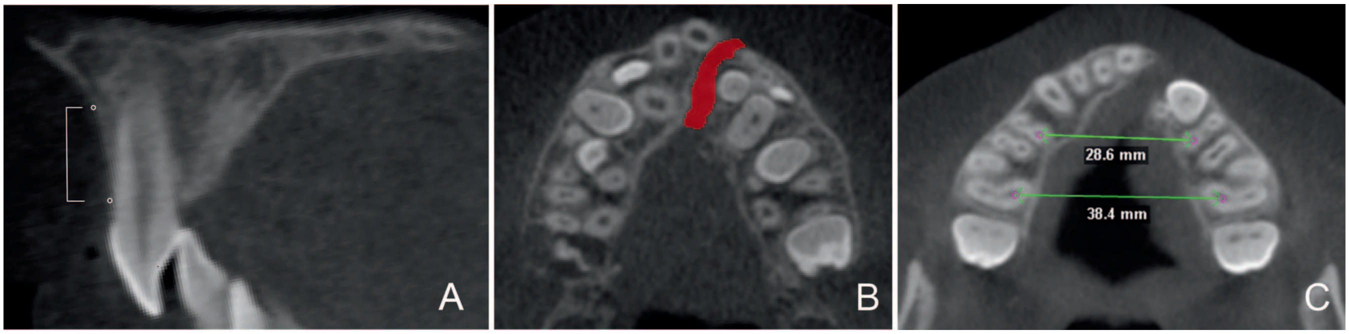

Figure 2. (A) Upper and lower limits of the alveolar cleft. (B) Label maps of the alveolar cleft were performed in each slice between the upper and lower limits for the calculation of the cleft volume. (C) AWA and AWP measurements.

posterior nasal spine (PNS), (3) posterior edge of the greater palatine foramen (PF) in the first axial slice from bottom to top that included the full contour of the foramen of the cleft (PF cleft) and (4) noncleft sides (PF noncleft); (5) the lowest point of the zygomaticomaxillary suture on the cleft side (Z cleft), and (6) noncleft sides (Z noncleft). The assessment of the displacement of the landmarks between T0 and T1 was carried out taking into account the projected linear displacement of landmarks calculated in the X (right–left), Y (anterior–posterior), and Z (superior–inferior) planes; thus, the Euclidean 3D displacement. The angular changes were estimated as pitch (rotation over the X axis), roll (rotation over the Y axis), and yaw (rotation over the Z axis).[20] The following parameters were assessed: (1) displacement of ANS, (2) displacement of the zygomaticmaxillary point, (3) displacement of the PF, (4) palatal plane angular change (angle formed between the lines that united the ANS and PNS at T0 and T1 on the noncleft side), (5) zygomaticomaxillary plane angular change, (6) PF plane angular change, (7) angle formed between the lines that united PF and Z at T0 and T1 on the noncleft side, and (8) angle formed between the lines that united PF and Z at T0 and T1 on the cleft side. Semitransparent overlays and color mapping of the corresponding anatomical changes from T0 to T1 were generated for visual analysis (Figure 4).

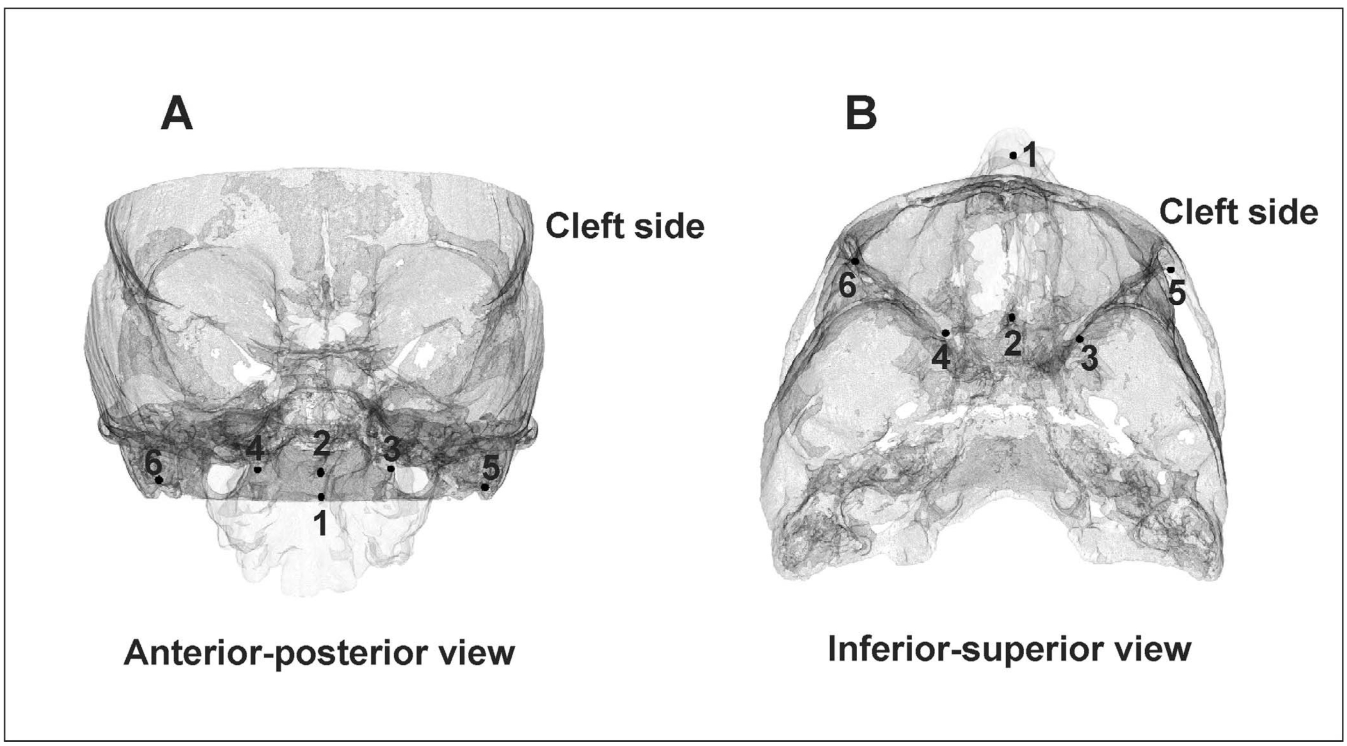

Figure 3. Landmarks for the MBB measurements: (1) ANS, (2) PNS, (3) PF on the cleft side, (4) PF on the noncleft side, (5) zygomaticomaxillary suture on the cleft side, (6) zygomaticomaxillary suture on the noncleft side.

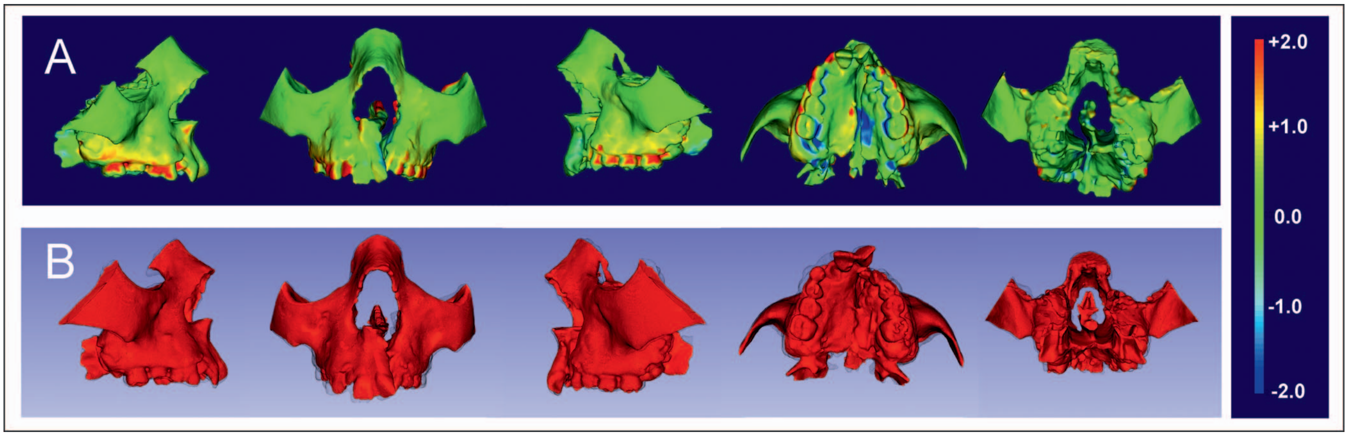

Figure 4. (A) Closest point color mapping. (B) Semitransparent overlays illustrating the dentoskeletal changes. Color range varied from 2 mm to –2 mm. Green means no change from prior to rapid maxillary expansion to after removal of the expander. Hot colors (red and yellow) mean outward change, whereas cold colors (dark and light blue) mean inward change.

Statistical Analysis

A total of 25 randomly selected scans were remeasured after a 2-week interval. Intraclass correlation coefficients and the Springate method[18] were employed to assess agreement and random errors, respectively. The Kolmogorov-Smirnov test was used to assess the normal distribution and homoscedasticity of all analyzed variables. Paired *t*-test or Wilcoxon test was used to evaluate changes from T0 to T1. The level of significance was set at 5%.

RESULTS

The intraclass correlation coefficient was greater than 0.8, and random error varied between 0.6 mm and 1.2 mm for linear and from 2.3 to 3.7 degrees for angular measurements.

Tables 1 and 2 show the changes between T0 and T1 as well as the effect size and the post hoc power. Qualitative visual assessments (semitransparent overlays and color mapping with closest points) of the dentoskeletal changes are illustrated in Figure 4.

No significant differences were found in the three NS measurements (–0.1 for the MLA, $P = .440$; 0.2 for the PBA, $P = .168$; and –0.1 for the DMDP, $P = .070$; Table 1).

Table 1 shows the statistically significant increases of the anterior (14.2%) and posterior (7.7%) alveolar width dimensions following RME. Increases of 3.8 mm in the anterior region (T0, 26.8 mm vs T1 30.6 mm; $P < .001$) and 3.2 mm in the posterior region (T0, 40.1 mm vs T1 43.2 mm; $P < .001$) were measured.

The increase of the ACV from 572.37 mm^3 to 684.82 mm^3 (a 19.6% difference) was statistically significant ($P = .001$; Table 1).

Qualitative visual assessment with color mapping (Figure 4A) and the semitransparent overlays (Figure 4B) showed that skeletal displacement at the level of the basal bone was smaller than 1 mm in all patients, suggesting that RME had minor or no clinically significant effects. The major changes after RME were found in the dentoalveolar region. Buccal dental displacement, identified in red, was found in all patients (red color, changes >2 mm). Minor changes were observed in the alveolar region (yellow color, changes >1 mm). Color mapping of most of the patients displayed predominantly a green color in the basal bone region, which indicated no changes within the MBB (green color, no changes). Visual assessments confirmed the quantitative point-to-point measurements that did not identify skeletal changes (Table 2).

Table 2 shows small and clinically insignificant angular changes, varying from 0° to 1.7°. The maxilla did not display any clinically significant rotation (pitch, roll, and yaw) after RME in patients with UCLP.

DISCUSSION

CLP is a congenital anomaly that has a pronounced effect on the nasomaxillary complex, affecting craniofacial development and severely compromising airway function.[2,3] As an important part of the interdisciplinary treatment of patients with clefts, RME is frequently performed to restore the maxillary transverse dimension prior to alveolar bone grafting. Its effects have been extensively investigated in the literature.[19,21] However, 3D studies that evaluated the changes in the NS architecture and in the volume of the alveolar cleft post-RME are lacking. The results of this showed that the NS deviation did not undergo significant changes after RME despite the significant increase in the ACV and the maxillary transverse dimension.

Recent advances in CBCT and related software have made diagnosis and treatment planning for patients with clefts more accurate as a result of the higher quality of the images. In addition, quantitative assessments and 3D visual analysis of the naso-maxillary complex following RME treatment with the voxel-based method used in this study offered advantages over other approaches because thousands of voxels were used rather than a limited number of landmarks. In addition, this method was not observer dependent.[22]

The literature is controversial regarding the effects of RME on NS deviation, which occurs more frequently in patients with clefts than in patients without clefts.[23] It was reported that NS deviation tended to straighten,[10,24] remained unaltered,[11,12] interfered with the expansion of the maxilla, or moved along with it during expansion in patients without clefts.[25] In addition, the osteotomy of the NS is generally defended to prevent deviation of the septum during the separation of the maxillary bones,[25] although no significant differences were found between cases with and without osteotomy.[26] This study found that RME did not interfere with the NS of patients with UCLP. This must be taken into consideration in the interdisciplinary treatment plan.

Despite the capacity of the RME to correct the transverse maxillary deficiency, it is expected that the separation of the maxillary halves caused by the orthopedic forces will increase the alveolar cleft dimension.[27] Although previous studies measured the cleft defect volumetrically,[28,29] the current study was the first to calculate the extent to which the volume increased post-RME. Clinicians should be aware that performing RME in patients with CLP might provide an average increase of approximately 20% in alveolar defect volume in the cleft region. This mean volumetric gain should be considered for planning bone grafting, anterior dental implants, and retention protocols for stability of the maxillary transverse dimension. Interestingly, the transverse gain, which was greater in the anterior part of the maxilla, was achieved by dentoalveolar compensation only, without basal bone displacement, a result that was different from previous reports.[6,19] Variations in the methodology, especially of the basal bone parameters, might explain this difference. In addition, the most fragile link of the bilateral maxillary components in patients with UCLP is the cleft area rather than the median palatal suture. Therefore, the heavy load provided by RME most likely laterally displaced the dentoalveolar segments, not affecting the basal bone tridimensionally, as evidenced by the current data.

A limitation of the current study was the absence of a control group. However, it would be unethical to deny orthodontic treatment to UCLP patients at the appropriate time to compose a comparison group of individuals. This drawback might have been overcome by the short experimental time (3 months) where the growth and development of the maxilla did not create substantial dentoalveolar and skeletal modifications. Thus, the changes identified in the current study represented the real changes promoted by RME in patients with UCLP.

This study demonstrated that the observed changes originated only from dentoalveolar compensations. This finding may be related to the frequent relapse of RME that is observed clinically during the follow-up of patients with UCLP.[30] Further studies should be performed to better understand the maxillary changes of performing RME in patients with different types of CLP.

CONCLUSIONS

- RME causes no change in the NS of patients with UCLP.
- ACV significantly increased (~20%) after RME.
- The increase in the maxillary transverse dimension in patients with UCLP was achieved by dentoalveolar compensation only, without basal bone displacement.

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