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Bone-anchored maxillary protraction therapy in patients with unilateral complete cleft lip and palate: 3-dimensional assessment of maxillary effects

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Abstract

Introduction—The aim of this study was to 3-dimensionally assess the treatment outcomes of bone-anchored maxillary protraction (BAMP) in patients with unilateral cleft lip and palate.

Methods—The cleft group comprised 24 patients with unilateral cleft lip and palate and Class III malocclusion with mean initial and final ages of 11.8 and 13.2 years, respectively. The noncleft group comprised 24 noncleft patients with Class III malocclusion with mean initial and final ages of 11.9 and 12.9 years, respectively. Cone-beam computed tomography examinations were performed before and after BAMP therapy in both groups and superimposed at the cranial base. Three-dimensional displacements of maxillary landmarks were quantified and visualized with color-coded maps and semitransparent superimpositions. The *t* test corrected for multiple testing (Holm-Bonferroni method), and the paired *t* test was used for statistical comparison between groups and sides, respectively ($P < 0.05$).

Results—BAMP produced anterior (1.66 mm) and inferior (1.21 mm) maxillary displacements in the cleft group with no significant differences compared with the noncleft group. The maxillary first molars of the cleft group showed significantly greater medial displacement than did those in the noncleft group. The zygoma showed significantly greater lateral displacement at the cleft side compared with the noncleft side.

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Conclusions—BAMP caused similar amounts of maxillary protraction in patients with and without unilateral cleft lip and palatem with discrete differences between the cleft side and the noncleft side.

In patients with complete cleft lip and palate, maxillary growth is often compromised by the restrictive forces from the lip and palate repair.[1] In unoperated patients with unilateral complete cleft lip and palate (UCLP), the maxilla is intrinsically retruded.[2] Such maxillary retrusion is often more severe in operated patients, where the maxillary anteroposterior position decreases on average by 5.4° from 5 to 18 years of age.[3] As a result, patients with cleft lip and palate often show a Class III skeletal pattern associated with anterior crossbite. The GOSLON index is a “reliable, robust, and simple mean” to assess the dental arch relationship for patients with UCLP, with scores from 1 to 5.[4] Scores 1 and 2 represent, respectively, excellent and good dental arch relationships, requiring simple or no orthodontic treatment; score 3 describes a fair dental relationship, requiring a more complex orthodontic treatment, such as maxillary expansion and protraction to compensate for the sagittal and transversal discrepancies; and scores 4 and 5 show poor dental arch relationships and often need orthognathic surgery correction.[1] An intercenter study showed that between 6 and 12 years of age, approximately 35% of the patients were classified as GOSLON index 3, 30% as GOSLON index 4, and only 6% as GOSLON index 5.[4]

For years, the most common therapy for a maxillary deficiency in patients with complete cleft lip and palate with a mild discrepancy consisted of rapid maxillary expansion followed by facemask therapy for maxillary protraction. Over the past decade, new treatment protocols have been proposed aiming to control dental compensations and increase the amount of skeletal maxillary protraction with a facemask.[5,6] Bone anchorage has also been used to substitute conventional dental anchorage for maxillary protraction with a facemask in patients with clefts.[6]

Recent studies have shown marked skeletal changes after bone-anchored maxillary protraction (BAMP) in noncleft Class III patients.[7] Therefore, the purpose of this study was to 3-dimensionally assess maxillary changes with BAMP therapy in patients with UCLP. The null hypothesis was that no differences are observed for maxillary outcomes in patients with UCLP compared with noncleft subjects.

MATERIAL AND METHODS

Institutional research ethics committee approval was obtained from the University of Michigan. The sample size calculation was based on preliminary statistics including the first 10 patients of the experimental group. For a standard deviation of 1.49 mm and a minimal intergroup difference of 1.5 mm to be detected, a sample of 17 patients was required to provide statistical power of 80% with an alpha of 0.05.

The cleft group (CG) consisted of 24 patients with UCLP and maxillary retrusion, treated consecutively at the Hospital for Rehabilitation of Craniofacial Anomalies, University of São Paulo. The CG was prospectively treated, and the inclusion criteria were age between 10 and 13 years old, clinical presence of the mandibular permanent canines, secondary alveolar bone graft at least 3 months before the miniplates were installed, and maxillary deficiency varying from moderate to severe (GOSLON index, 3–5). The exclusion criteria were patients with syndromes and bad initial oral hygiene. The comparison noncleft group (NCG) consisted of secondary data analysis[8] of 25 Class III patients without cleft lip and palate, consecutively treated with BAMP therapy in a private practice in Brussels, Belgium. The samples are described in Table I.

In the CG, miniplates were installed bilaterally at least 3 months after the secondary alveolar bone graft procedure using recombinant human bone morphogenetic protein-2 (Medtronic; Fridley, Minnesota); 3 months was the mean time for new bone formation in the cleft region. Maxillary miniplates were installed in the infrazygomatic crest, and mandibular miniplates were installed between the permanent lateral incisor and the canine, as described by de Clerck et al[7] (Fig 1). Three weeks after the miniplates were placed, the patients were instructed to wear the intermaxillary elastics (G&H Orthodontics, Franklin, Ind) full time, connecting the maxillary and mandibular miniplates. When decomposed, the force vector would not only have anterior and inferior directions, but also a lateral direction because the distance between the right and left miniplates was greater in the maxilla than in the mandible, showing a lateral component in the posterior region of the maxilla, where the miniplates were installed. The force of the elastics was measured bilaterally and started with 75 g in each side in the first month, 150 g in the second month, and 250 g from the third month to the end of active treatment, similar to the protocol previously described for patients without oral clefts.[7] The patients were instructed to wear the elastics 24 hours per day and replace them twice a day: early morning and night. Elastics were worn during meals. No facemask was used during BAMP treatment.

Cone-beam computed tomography (CBCT) examinations were obtained before (T1) and after (T2) treatment with intervals of 18 and 12 months for the CG and the NCG, respectively. In the CG, 2 patients were lost during the follow-up because of treatment interruption, 1 patient was excluded due to maxillary miniplate instability and recurrent bad oral hygiene, and 1 patient was excluded due to movement artifacts during the CBCT examination. The study sample consisted then of 20 patients in the CG. One patient was excluded from the NCG for missing CBCT data.

Three-dimensional surface models were created from the DICOM files in 6 steps.

1. **1.** Create a volumetric label map: using ITK-SNAP,[9] an open-source software (version 2.4.0; www.itksnap.org), the cranial base and the maxilla were segmented for the T1 and T2 scans.

2. **2.** Create a virtual 3-dimensional (3D) surface model: using 3D Slicer (version 4.4; www.slicer.org), another open-source software, the virtual 3D surface models were created from the T1 and T2 volumetric label maps.

3. **3.** Head orientation: the 3D coordinate system of the 3D Slicer was kept fixed to be used as a reference to consistently orient the 3D models of all patients. Using axial, coronal, and sagittal views of the 3D models, the T1 model was moved to match the midsagittal plane (defined by glabella, crista galli, and basion) vertically and coincident to the sagittal plane of the 3D coordinate system. The Frankfort horizontal plane was oriented to match the axial plane, and the

horizontal infraorbitale (most inferior point of the left and right orbitals) line was oriented to be coincident to the coronal plane.[10]

4. Three-dimensional cranial base superimposition: the 3D superimposition registered in the cranial base was performed in 2 steps. Using 3D Slicer, the T2 scan was manually approximated to the T1 oriented scan, and using the anterior cranial fossa label map as a best fit reference, a fully automated voxel-based registration was performed in 3D Slicer.[11] The matrix generated from the registration of T2 over T1 was applied to the T2 scan, volumetric label map, and 3D surface model also in 3D Slicer.
5. Landmark identification: landmarks were placed at the T1 and T2 surface models using the Q3DC tool in the 3D Slicer software as shown in Table II and Figure 2.
6. Quantitative measurements: 3D linear distances and the amount of directional changes in each plane of 3D space (x, y, and z: respectively the mediolateral, anteroposterior, and superoinferior axes) were measured between corresponding coordinates of landmarks placed in the T1 and registered T2 surface models. Anterior, inferior, and lateral displacements were considered positive values; posterior, superior, and medial displacements were considered negative values. Color-coded surface distance maps and semi-transparent superimpositions were used to visually demonstrate the overall maxillary changes in the CG.

Statistical analysis

Intraclass correlation coefficients (ICC) with a confidence level of 95% were used in 10 patients randomly selected from both group to assess the reproducibility of the x, y, and z coordinates of the landmarks placed at T1 and T2.

The statistical analysis was performed with the SPSS Statistical Software Package (version 21.0; IBM, Armonk, NY). Average values from the right and left sides were determined for all bilateral anatomic points. All variables showed normal distributions with the Kolmogorov-Smirnov test. Intergroup comparisons were performed with independent *t* tests corrected for multiple testing (Holm-Bonferroni method). The comparison between cleft and noncleft sides was performed using dependent *t* tests. The level of significance was set at 0.05.

RESULTS

Very good intraexaminer agreement was observed. The ICC result for each variable is shown in Table III.

The mean values, standard deviations, and statistical comparisons between the CG and NCG are given in Tables IV and V. A statistically significant difference between the CG and the NCG was found only for the first molar: the CG showed a medial displacement of 0.10 mm (0.76), and the NCG showed a lateral displacement of −0.76 mm (0.83) (Table IV).

Regarding the symmetry of the maxillary displacement in the CG, it was found that only the lateral displacement of the zygomatic point in the cleft side (0.69 ± 1.03 mm) was significantly greater than the contralateral side (0.13 ± 0.76 mm) (Table V). From a superior view, Figure 3 illustrates the slight asymmetry in maxillary anterior displacement in the CG.

Semitransparent superimpositions of the CG and closest-point color-coded surface distance maps of the CG and the NCG are shown in Figures 3 through 5.

DISCUSSION

Maxillary protraction therapy in patients with cleft lip and palate has been an important topic of discussion because it is a minimally invasive procedure designed to decrease skeletal discrepancies in these patients. Many studies have reported the short-term maxillary growth response to facemask therapy using 2-dimensional lateral cephalometric measurements.[12] However, 2-dimensional lateral images can only show the changes in an anteroposterior or a superoinferior direction as a 2-dimensional projection of a 3D structure. They cannot evaluate transverse changes or detect subtle differences between the greater and lesser segments of a cleft. With a 3D tool in this study, it was possible to visualize and measure 3D linear distances and the directional changes in their x, y, and z components and compare the symmetry between sides. Landmark-based measurements have been validated as an accurate and reliable method in 3D studies.[13]

This is the first study to assess 3D outcomes of bone-anchored maxillary protraction in patients with UCLP. Even though it showed impressive results in patients without clefts, there was great concern on what to expect from this therapy in patients with clefts, since their maxillary growth is under negative influences from the fibrous scar tissues. Anatomic landmarks representing the median structures (A-point and maxillary central incisor) showed similar overall changes between the CG and the NCG (Table IV). The amount of maxillary incisor anterior displacement in this study was within the range observed for maxillary orthopedic protraction.[5–8] Even though statistically significant differences were not detected for lateral displacements between groups, the maxillary incisors in the CG showed a tendency to drift toward the grafted area.

The mean 3D displacement of the maxillary first molars showed similar magnitudes in both groups. However, the first molar was displaced medially in the CG, and a lateral displacement was observed in the NCG (Table IV). Two factors might be associated with this medial displacement in patients with UCLP: a palatal defect, and relapse of the maxillary expansion before the alveolar bone graft.

The overall treatment results were statistically similar when the cleft side was compared with the noncleft side at orbitale, infraorbital foramen, and maxillary first molar landmarks in 3 dimensions and every directional displacement; this was expected, since successful bone graft surgery was performed before the protraction therapy (Table V; Fig 3). The lateral displacement of the zygomatic bone on the cleft side showed a significantly greater lateral displacement when compared with the noncleft side (Table V); this could be related to the fragility of the cleft segment.[14] Even though bone graft surgery was performed at the alveolar region, the defect originating from the cleft might have affected, in smaller proportions, other bone structures, and therefore the cleft segment was more exposed to the lateral force of growth associated with the elastics.[14]

Even though few significant differences were found, a high level of individual variations was observed for maxillary outcomes in patients with UCLP, as can be seen in Figures 3 through 5 and Table VI. These results corroborate previous studies of maxillary protraction and could be associated with different stages of skeletal maturation of these patients.[5,15] Even though the gap between the initial and final CBCT scans was different between groups, it is still unknown whether the extra 6 months in the CG could be related to inherent characteristics of the cleft, such as tissue fibrosis, or whether it could be related to the learning curve, since this was the first experience of this rehabilitation center with BAMP therapy. The maxillary protraction outcomes in patients with cleft seen in this study might be related to the BAMP therapy and might also be underestimated in this study because, as described in the literature, the maxillary anterior displacement is decreased in UCLP patients compared with noncleft patients.[3,16] The main limitation of this study was the absence of an untreated control group with UCLP, which was not feasible for ethical reasons.

Future studies should increase the sample size, verify the long-term stability of growth changes, and compare short-term and long-term outcomes from facemask therapy. Additionally, the influence of growth pattern, type of cleft, and skeletal maturation on BAMP outcomes should be tested.

CONCLUSIONS

Based on these results, the null hypothesis was accepted. The BAMP therapy produced a symmetric and similar protraction of the maxillary region in patients with and without oral clefts. This therapy may improve facial esthetics by minimizing the maxillomandibular discrepancy and increase self-esteem during adolescence.

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Fig 1.
Anterior and lateral intraoral photos of the installation of intermaxillary elastics in a patient in the CG.

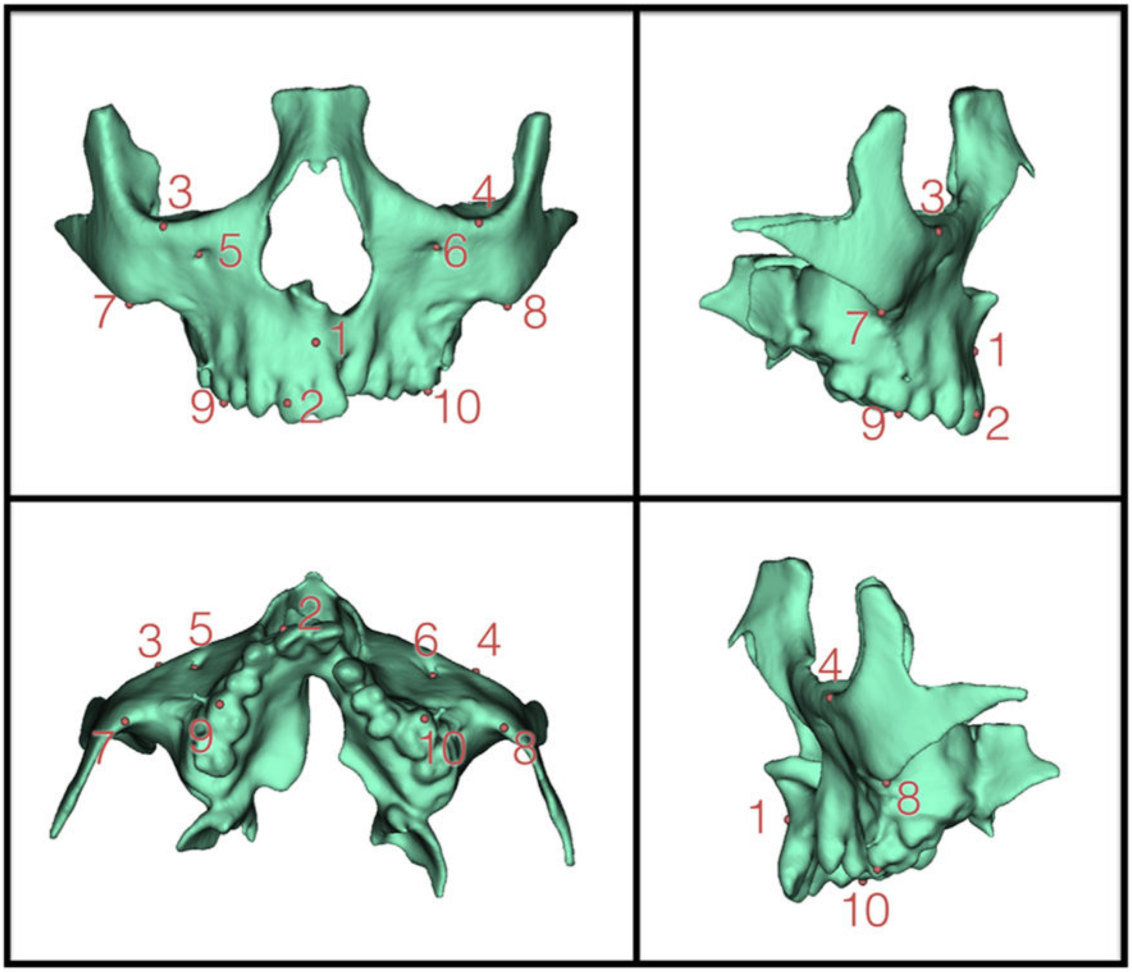

Fig 2.

Landmarks placed in the 3D surface model: (1) A-point (A); (2) center of the central incisor on the noncleft side or the right central incisor of the NCG (U1); (3) and (4) right and left infraorbitale points (Or); (5) and (6) right and left infraorbital foramina (IOF); (7) and (8) right and left inferior points of the zygomatic bone (Zyg); (9) and (10) mesial buccal cusps of the permanent first molar on the right and left sides (U6).

Fig 3.

Semitransparency superimpositions of the T1 (*red*) and T2 (*white*) 3-dimensional surface models in a superior view, cropped at the level of the anterior nasal spine for all patients in the CG.

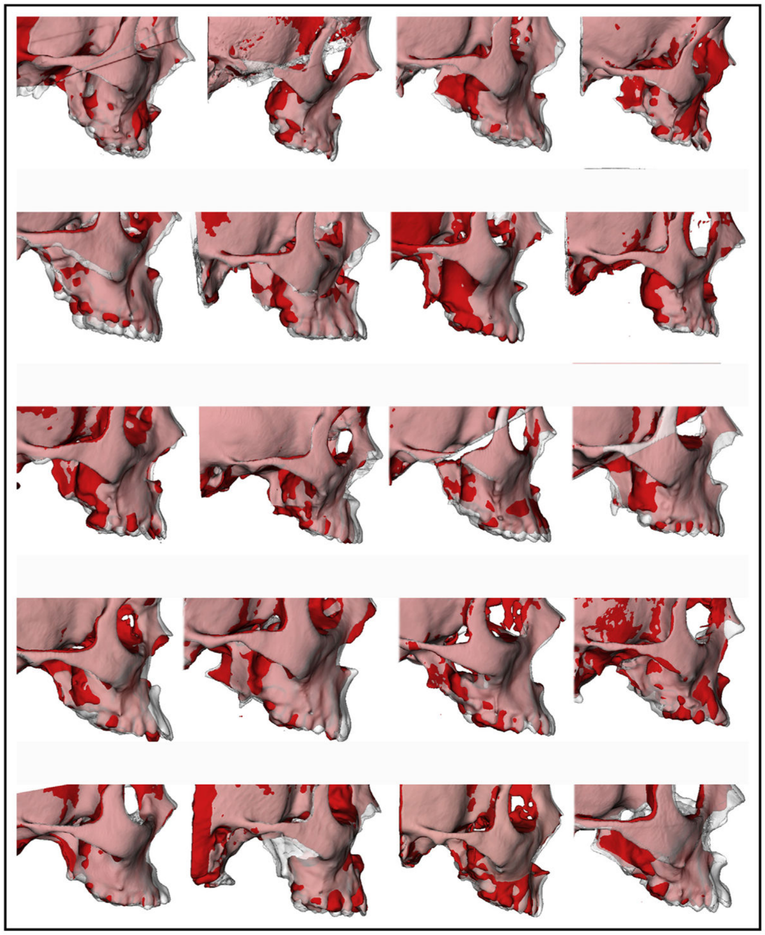

Fig 4.

Semitransparency superimpositions of the T1 (*red*) and T2 (*white*) 3-dimensional surface models in a lateral view for all patients in the CG.

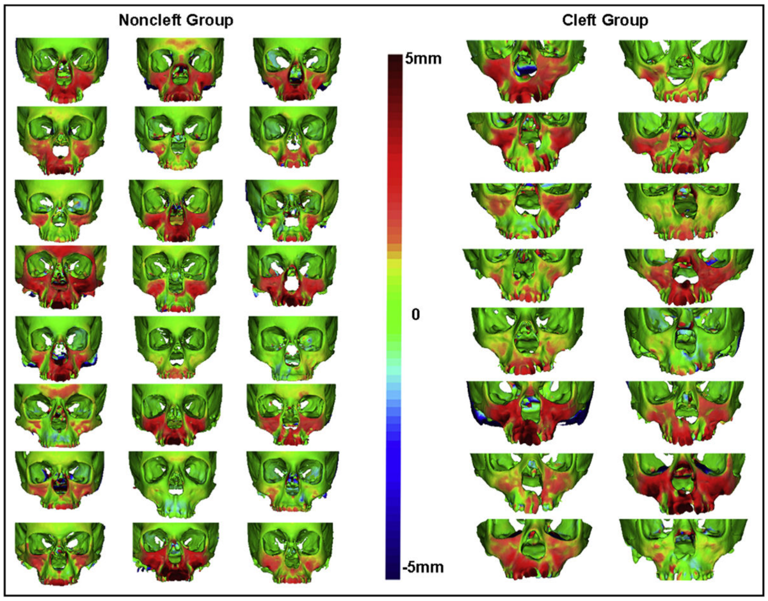

Fig 5.

Color-map images of the anteroposterior directional changes (y component) between T1 and T2 in anterior views for both samples (range, −5 to +5 mm). *Shades of red* represent anterior displacement; *shades of green*, no displacements; and *shades of blue*, posterior displacement.

Table I

Sample description

Group	n (cleft side right/left)	Male/female	Mean (SD) age at T1 CBCT	Mean (SD) age at T2 CBCT	Wits appraisal mean (SD)
CG	24 (6/18)	17/7	11.8 y (±9 mo)	13.2 y (±8 mo)	−7.13 mm (3.13)
NCG	24	10/15	11.9 y (±14 mo)	12.9 y (±16 mo)	−4.8 mm (2.8)

Table II

Description of the landmarks

Maxillary central incisor	Landmark placed at the center of the clinical crown of the noncleft side maxillary central incisor (CG) or the right central incisor (NCG).
A-point (A)	Landmark placed at the most posterior point of the concavity of the anterior region of the maxilla, as in the cephalometric analysis; it should be seen in both left and right views.
Orbitale (Or)	Landmarks placed at the most inferior point of the left and right orbitals.
Infraorbital foramen (IOF)	Landmarks placed at the entrance of the right and left infraorbital foramina.
Zygomatic (Zyg)	Landmarks placed in the most inferior portion of the inferior border of the right and left zygomatic bones.
Maxillary permanent first molar (U6)	Landmarks placed at the buccal-mesial occlusal cusp of the right and left permanent first molars.

Table III

Intraexaminer results from the ICC test

	x	y	z	3D
U1	0.97	1.00	0.77	0.95
A	0.80	0.96	0.98	0.94
Or.R	0.99	0.87	0.79	0.82
Or.L	0.86	0.82	0.91	0.83
IOF.R	0.87	0.92	0.83	0.95
IOF.L	0.90	0.85	0.93	0.89
Zyg.R	0.76	0.87	0.94	0.84
Zyg.L	0.78	0.83	0.96	0.89
U6.R	0.92	0.89	0.96	0.97
U6.L	0.91	0.94	0.86	0.92

3D, 3-dimensional; *R*, right; *L*, left.

Table IV

Descriptive (means and standard deviations) and statistical analyses of the comparison between the CG and the NCG

	Medial-lateral plane (x) (mm)		Anteroposterior plane (y) (mm)		Superior-inferior plane (z) (mm)		Total linear displacement (3D) (mm)	
	CG group	NCG group	CG group	NCG group	CG group	NCG group	CG group	NCG group
Landmarks	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Central incisor	−0.48 (1.50)	−0.28 (1.10)	2.98 (2.11)	3.50 (2.18)	0.84 (1.52)	1.76 (1.32)	3.89 (1.85)	4.50 (1.62)
	$P = 0.627$		$P = 0.437$		$P = 0.043$		$P = 0.266$	
A-point	−0.36 (1.07)	−0.32 (1.19)	1.66 (1.54)	2.37 (1.83)	1.21 (1.64)	0.63 (1.43)	2.61 (1.89)	3.20 (1.59)
	$P = 0.906$		$P = 0.173$		$P = 0.220$		$P = 0.283$	
Orbitale	0.45 (0.54)	0.38 (0.58)	1.30 (0.67)	1.36 (0.98)	0.56 (0.67)	0.34 (0.81)	1.77 (0.83)	1.83 (0.96)
	$P = 0.670$		$P = 0.817$		$P = 0.338$		$P = 0.806$	
Infraorbitale foramen	0.17 (0.72)	−0.20 (0.75)	1.70 (1.20)	1.44 (1.24)	0.69 (0.91)	0.58 (1.03)	2.47 (0.99)	2.24 (1.10)
	$P = 0.085$		$P = 0.408$		$P = 0.809$		$P = 0.436$	
Zygomatic	0.41 (0.79)	0.55 (0.81)	1.63 (0.93)	1.77 (1.21)	1.38 (1.24)	1.27 (1.05)	2.61 (1.06)	2.76 (0.95)
	$P = 0.573$		$P = 0.661$		$P = 0.761$		$P = 0.639$	
First molar	−0.76 (0.83)	0.10 (0.76)	3.21 (1.63)	3.27 (1.71)	2.08 (1.41)	2.26 (1.09)	4.31 (1.65)	4.41 (1.38)
	$P = 0.001^{*}$		$P = 0.904$		$P = 0.628$		$P = 0.840$	

3D, 3-dimensional.

* Statistically significant.

Table V

Descriptive and statistical analyses of the comparison between cleft and noncleft sides

	Medial-lateral (x) (mm)		Anteroposterior (y) (mm)		Superior-inferior (z) (mm)		Total linear displacement (3D) (mm)	
	Cs	NCs	Cs	NCs	Cs	NCs	Cs	NCs
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Orbitale	0.64 (1.01)	0.27 (0.34)	1.24 (0.73)	1.36 (0.77)	0.47 (0.72)	0.65 (0.78)	1.84 (0.89)	1.70 (0.86)
	$P = 0.13$		$P = 0.46$		$P = 0.24$		$P = 0.29$	
Infraorbitale foramen	0.04 (1.00)	0.30 (1.03)	1.68 (1.52)	1.73 (1.12)	0.53 (0.87)	0.86 (1.25)	2.38 (1.17)	2.56 (0.98)
	$P = 0.23$		$P = 0.91$		$P = 0.52$		$P = 0.9$	
Zygomatic	0.69 (1.03)	0.13 (0.76)	1.54 (0.84)	1.72 (1.19)	1.11 (1.05)	1.59 (1.47)	2.46 (0.90)	2.76 (1.39)
	$P = 0.01$*		$P = 0.38$		$P = 0.05$		$P = 0.19$	
First molar	−0.45 (1.12)	−1.08 (1.28)	3.14 (1.49)	3.28 (1.90)	1.94 (1.39)	2.21 (1.68)	4.09 (1.54)	4.54 (2.00)
	$P = 0.12$		$P = 0.56$		$P = 0.33$		$P = 0.16$	

3D, 3-dimensional; *Cs*, Cleft side; *NCs*, noncleft side.

* Statistically significant.

Table VI

Three-dimensional displacements (mm) of the variables A-point and U1 of all patients in the CG and NCG

	A-point		U1	
Patient	**CG**	**NCG**	**CG**	**NCG**
1	5.39	2.62	8.24	3.46
2	1.82	6.05	1.9	8.08
3	0.62	3.83	5.06	5.08
4	2.57	3.21	5.07	3.33
5	0.88	1.72	1.39	2.57
6	1.85	2.71	2.61	3.99
7	5.97	3.67	7.44	4.34
8	2.74	4.99	3.75	6.36
9	1.78	2.12	2.27	3.36
10	4.32	3.14	4.16	3.44
11	1.43	1.31	3.44	1.84
12	3.35	4.84	6.01	5.61
13	4.17	3.97	4.46	5.46
14	1.36	3.5	2.51	5.93
15	2.65	3.12	4.49	6.69
16	6.61	0.54	3.84	2.46
17	3.45	5.08	4.44	5.71
18	0.17	1.18	1.77	3.17
19	1.00	2.42	2.48	2.83
20	0.14	2.7	2.54	2.87
21		2.99		5.65
22		4.68		5.55
23		4.24		5.62
24		4.41		*

*One patient was excluded from the U1 measurement of the NCG due to an artifact in the buccal surface of the maxillary central incisor.