Original Article

Dental arch size and shape after maxillary expansion in bilateral complete cleft palate:
A comparison of three expander designs

Fernando Pugliese[a]; Juan Martin Palomo[b]; Louise Resti Calil[c]; Arthur de Medeiros Alves[d]; José Roberto Pereira Lauris[e]; Daniela Garib[f]

ABSTRACT
Objective: The objective of this study was to compare the effects on upper dental arch size and shape after maxillary expansion with Hyrax, Quad-helix, and a differential opening expander in bilateral cleft lip and palate (BCLP) patients.
Materials and Methods: Seventy-five BCLP patients were divided into three groups: Hyrax (H), Quad-helix (QH), and Expander with differential opening (EDO). Digital models were obtained before (T1) and after 6 months (T2) of maxillary expansion. Twelve landmarks were placed by one investigator on T1 and T2 dental models of each group, and *x,y* coordinates for each landmark were collected. For dental arch size analysis, centroid size of each dental arch at T1 and T2 was calculated from raw coordinates and was used as the measure of size. Procrustes Analysis was performed for dental arch shape analysis. Analysis of variance was used to compare the groups for size and shape differences ($P < .05$).
Results: There were no significant dental arch size differences among the expanders at T1 or T2. Differences in arch shape were found between all groups at T2. Intragroup arch shape showed a significant variation for the QH and EDO groups. while it remained stable in the H group.
Conclusions: Both the QH and the EDO create dental arch shape changes with greater intercanine than intermolar increase. The H does not change the dental arch shape. (*Angle Orthod.* 2020;90:233–238.)

KEY WORDS: Expansion; Cleft; Arch shape

[a] Visiting Professor, Department of Orthodontics, School of Dental Medicine, Case Western Reserve University, Cleveland, Ohio.
[b] Professor and Residency Director, Department of Orthodontics; and Director, Craniofacial Imaging Center, Case Western Reserve University, Cleveland, Ohio.
[c] Postgraduate Student, Department of Orthodontics, Bauru Dental School, University of São Paulo, Bauru, Brazil.
[d] Professor, Department of Orthodontics, Federal University of Rio Grande do Norte, Natal, Brazil.
[e] Professor, Department of Pediatric Dentistry, Orthodontics and Community Health, Bauru Dental School, University of São Paulo, Bauru, Brazil.
[f] Associate Professor, Department of Orthodontics, Bauru Dental School and Hospital for Rehabilitation of Craniofacial Anomalies, University of São Paulo, Bauru, Brazil.
Corresponding author: Dr Fernando Pugliese, Department of Orthodontics, Dental School, Case Western Reserve University, 2124 Cornell Road, Cleveland, OH 44106
(e-mail: fdp10@case.edu)

Accepted: June 2019. Submitted: February 2019.
Published Online: August 30, 2019

INTRODUCTION

Cleft lip and palate is the craniofacial anomaly with the highest prevalence in the human population.[1] Bilateral complete cleft lip and palate (BCLP) is the most severe cleft lip and palate type, maintaining the embryological maxillary division and challenging the multidisciplinary treatment team.[2]

In untreated patients, the premaxilla maintains its anterior projection and the posterior segments tend to approximate, resulting in a narrow dental arch.[3] Lip and palate repair surgeries often have a negative influence on maxillary growth and development, resulting in maxillary dental arch constriction and maxillary sagittal deficiency.[4] As a consequence, anterior and posterior crossbites and maxillary arch perimeter reduction are frequently observed, and maxillary expansion is often required.[5] Many appliances have been used for maxillary expansion in cleft lip and palate patients, including the Quad-helix appliance (QH) and the Hyrax expander (H). Both appliances have been shown to be

Figure 1. A, Hyrax expander. B, Quad-helix expander. C, Expander with differential opening.

effective for maxillary dimension improvement, with the QH achieving a greater intercanine expansion.[6–8]

Transverse maxillary constriction in BCLP results in a triangular-shaped dental arch.[3] Intercanine distance decreases more markedly during growth than does the intertuberosity distance, requiring greater expansion in the anterior region.[9] For this reason, the expander with differential opening (EDO) was introduced for achieving different anterior and posterior amounts of expansion in BCLP.[10] EDO promoted a greater expansion in the anterior region of the maxillary dental arch, with no skeletal differences from the traditional Hyrax.[11] No previous morphological analysis of the expander outcomes was performed in BCLP. The purpose of this study was to compare the effects of H, QH, and EDO on maxillary dental arch size and shape in patients with BCLP.

MATERIALS AND METHODS

This retrospective study was approved by the ethics committee (protocol 1.991.298) of the Hospital for Rehabilitation of Craniofacial Anomalies at the University of São Paulo, Brazil. All patients with BCLP were treated in a single center from 2011 to 2013. The inclusion criteria for the study were age between 7 and 10 years; lip and palate repair, respectively, performed at 3 and 24 months of age; presence of first permanent molar; presence of maxillary arch constriction; and need for maxillary expansion. Exclusion criteria were associated syndromes, history of previous orthodontic treatment, and absence of teeth to support the expansion appliance. After searching patients' records, 75 patients with BCLP were initially selected (55 males and 20 females), with a mean age of 8.7 years.

The expanders (Figure 1) were supported by bands adapted to the first permanent molars or second deciduous molars. When bands were placed on second deciduous molars, a distal arm was present in order to include the permanent first molar. H and EDO also had C-shaped clasps bonded to the deciduous canines. In the H appliances, the screw was activated two quarter turns in the morning and two quarter turns in the evening until the posterior maxillary teeth palatal cusps were aligned with the mandibular posterior teeth buccal cusps. After the active phase, the appliance was kept for retention for 6 months.

QH appliances were constructed using 0.036-inch stainless-steel wire and activated 6 mm every 2 months until overexpansion of the molars was reached, using the same protocol as for the H group. QH anterior extensions were activated against the premolar and canine palatal surfaces, distally rotating the banded molars, until an approximately 2-mm overcorrection was reached in the canine region. After the expansion phase, the QH was also maintained for retention purposes for 6 months.

Both anterior and posterior screws of the EDO were activated two quarter turns in the morning and two quarter turns in the evening until the maxillary molar palatal cusps were aligned with the mandibular molar buccal cusps. On the following days, only the anterior

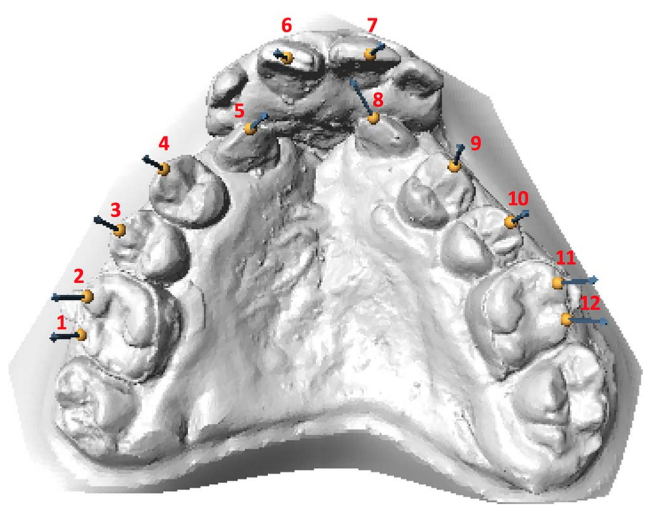

Figure 2. Twelve selected points on digital models: (1) Distobuccal cusp of the right first molar, (2) mesiobuccal cusp of the right first molar, (3) buccal cusp of the right second premolar*, (4) buccal cusp of the right first premolar*, (5) cusp of the right canine, (6) midpoint of the incisal edge of the right central incisor, (7) midpoint of the incisal edge of the left central incisor, (8) cusp of the left canine, (9) buccal cusp of the left first premolar*, (10) buccal cusp of the left second premolar*, (11) mesiobuccal cusp of the left first molar, and (12) distobuccal cusp of the left first molar. * indicates midpoint of the buccal ridge of deciduous molars.

Table 1. Upper Dental Arch Size Comparison by Sex (*t*-Test)[a]

	Male (n = 26)	Female (n = 17)	
Variable	Mean (SD)	Mean (SD)	*P*
T1 arch size	77.64 (6.63)	75.97 (6.08)	.41

[a] SD indicates standard deviation; T1, before maxillary expansion.

expander screw was activated until an approximately 2-mm overcorrection was achieved in the canine region. The amount of anterior region expansion depended on the severity of the maxillary constriction of each patient. The appliances were maintained as retainers for 6 months.

Dental models were obtained before expansion (T1) and 6 months after the active phase when the appliances were removed (T2). Two dental models from the group H were lost. Ten patients in each group were excluded during the analysis because of tooth absence due to the transitional dentition or because the expander was supported on the second deciduous molars.

The dental models were scanned using a 3Shape R700 three-dimensional scanner (3Shape A/S, Copenhagen, Denmark). After scanning, the digital models were imported into the software Stratovan Checkpoint (Stratovan Corporation, Davis, Calif). Twelve homologous landmarks, described in to a previous study,[12] were placed by one investigator on the T1 and T2 maxillary dental models (Figure 2). The *x,y* coordinates for each landmark were collected. The raw landmark coordinates were imported into the software MorphoJ (Klingenberg Lab, Manchester, UK).

For arch size analysis, the centroid size of each dental arch in T1 and T2 was calculated from the raw coordinates and used as a maxillary dental arch size measurement. For arch shape analysis, a Generalized Procrustes Analysis[13] was performed using the software MorphoJ. With this method, non-shape variation was removed from the raw data, expressing pure shape differences between groups. A mean shape dental arch was determined for each group and time point.

Statistical Analysis

The sample size was determined by the arch size analysis. For a minimum difference of 1.31 and a standard deviation of 0.98, each group required 12 participants for an alpha error of 5% and a test power of 80%.

Table 3. Intergroup Comparisons for Arch Shape at T1 and T2 (Analysis of Variance)[a]

Groups	Residual	*F*-Value	*P*
H T1 vs QH T1	0.0006578976	0.48	.9747
H T2 vs QH T2	0.0005744039	1.68	.0331*
H T1 vs EDO T1	0.0008460767	1.37	.1286
H T2 vs EDO T2	0.0005874717	1.94	.0086*
QH T1 vs EDO T1	0.0007489566	2.23	.0017*
QH T2 vs EDO T2	0.0005273134	2.75	<.0001*

[a] T1 indicates before maxillary expansion; and T2, after 6 months of maxillary expansion; H, Hyrax; QH, Quad-helix; and EDO, Expander with differential opening.

* Statistically significant at $P < .05$.

To determine the method error, the same investigator replaced the 12 landmarks in 100% of the sample after 3 weeks. The random error was calculated using intraclass correlation coefficient (ICC) for both *x* and *y* coordinate values. SPSS Statistics, version 23 (IBM, Armonk, NY), was used.

Male and female values were compared using a *t*-test (SigmaPlot 12.0) to assess sex dimorphism. The sample distribution was tested using the Shapiro-Wilk normality test. Intergroup comparisons for arch size were performed using analysis of variance (ANOVA). SigmaPlot 12.0 (Systat Software, San Jose, Calif) was used. The mean shapes of the maxillary dental arch were compared using ANOVA (Procrustes ANOVA)[13–15] in the software MorphoJ. Results were regarded as significant for $P < .05$.

RESULTS

ICCs showed a high degree of reliability for repeated landmark placement (0.999 for the *x* coordinates and 0.987 for the *y* coordinates). There were no significant dental arch size differences between males and females at T1 (Table 1), so the data for both sexes were combined.

There were no significant dental arch size differences among expanders, either at the pre- or postexpansion phase (Table 2).

Before expansion (T1), differences in arch shape was found between the QH and EDO groups (Table 3).

Table 2. Intergroup Comparison of Dental Arch Size at T1 and T2 (Analysis of Variance)[a]

	Hyrax (n = 13)	Quad-helix (n = 15)	EDO (n = 15)	
Variable	Mean (SD) 95% CI	Mean (SD) 95% CI	Mean (SD) 95% CI	*P*
T1 arch size	77.96 (6.90) 73.78–82.13	78.12 (7.05) 76.35–81.28	75.02 (5.08) 72.20–77.83	.343
T2 arch size	81.52 (7.96) 76.71–86.33	85.86 (5.85) 82.61–89.10	84.54 (5.19) 81.67–87.42	.200

[a] EDO indicates Expander with differential opening; SD, standard deviation; CI, confidence interval; T1, before maxillary expansion; and T2, after 6 months of maxillary expansion.

Table 4. Intragroup Variation for Arch Shape (Analysis of Variance)[a]

Groups	Residual	*F*-Value	*P*
Hyrax	0.0006992502	0.60	.9170
Quad-helix	0.0005446685	3.22	$<$.0001*
EDO	0.0007288090	3.14	$<$.0001*

[a] EDO indicates Expander with differential opening.
* Statistically significant at $P < .05$.

After expansion (T2), differences in arch shape were found between all groups (Table 3). Both the QH and EDO expanders changed the maxillary arch shape between T1 and T2, while the H expander showed no change in arch shape between T1 and T2 (Table 4).

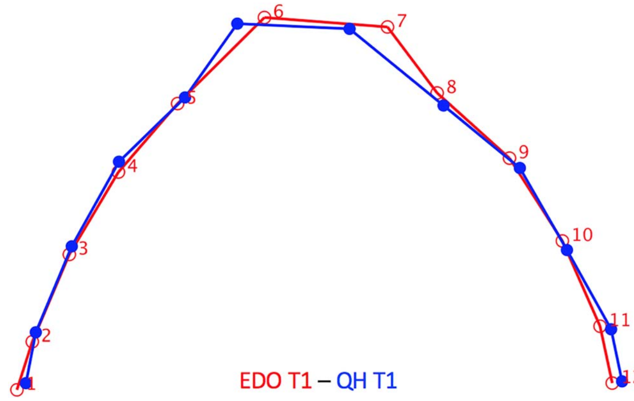

Figure 4. QH and EDO T1 Procrustes mean shape superimpositions. Premaxilla represented by points 6 and 7, referring to central incisors.

DISCUSSION

Geometric morphometrics has been used in biology and anthropology to observe species variation in evolutionary and biological processes.[16] Landmark-based geometric morphometrics involves summarizing shape regarding a landmark configuration, providing the intuitive visualization of the shape and the spatial localization of shape variation easily with graphical representation.[17] Morphometrics has been previously used as an alternative cephalometric analysis,[18,19] overcoming limitations of the traditional method that does not separate size from shape.[20,21] For the current study, centroid size was used as the size measurement. Centroid size is an isometric estimator of size, calculated as the square root of the sum of the squared distances between each landmark and the centroid of the form.[22] Generalized Procrustes Analysis was performed for shape analysis. With this method, non-shape variation was removed from the raw data by translating all dental arches to a common location (same centroid), rescaling all dental arches to unit centroid size and rotating all dental arches into an optimal least-squares alignment (Figure 3). All differences in location, size, and orientation were removed, expressing pure shape differences between groups.[23] Procrustes Analysis has been used in growth and maturation studies,[24,25] facial profile analysis,[26,27] skeletal shape evaluation,[28] and even in facial attractiveness.[29]

The main limitation of the method was the need for 12 homologous points to be placed on digital models for running the Procrustes superimposition. In the case of a missing tooth, a corresponding point was not placed and the subject was excluded from the sample.

There was no statistically significant difference in dental arch size between all groups at T1 and T2. Results at T2 were in agreement with those of Almeida et al.,[8] in which no differences were found between the orthopedic changes of H and QH expansions in BCLP patients. The greater intercanine expansion observed in groups QH and EDO may have been compensated for by a greater posterior movement of the maxillary incisor in these groups, which might explain the similarity in the dental arch size with group H at T2. Maxillary expansion achieved by the three appliances produced effective dental arch size changes in BCLP patients.

There were no sex differences found in dental arch size (Table 1). These results agree with those of Silva Filho et al.,[3] who showed that sex had no influence on the upper dental arch dimensions of cleft patients. It seems that the presence of the cleft in itself played a more important role in the determination of the dental arch dimensions.

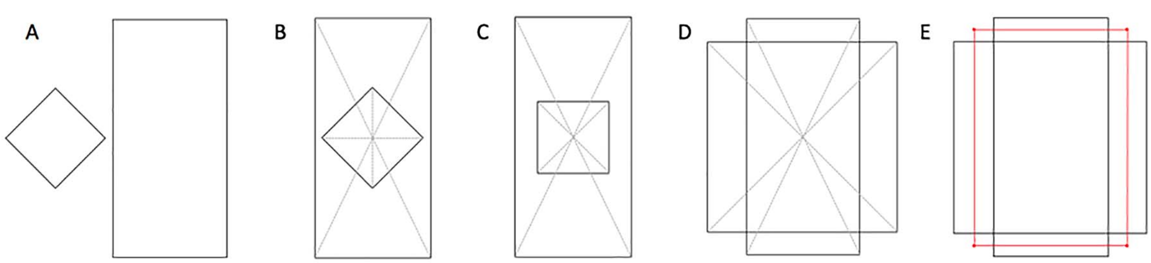

Figure 3. Generalized Procrustes Analysis. A, Two configurations. B, Translation to the same centroid. C, Rotation around the corresponding centroid until the sum of the squared distances between the homologous landmarks is minimized. D, Scaling the configurations to the same centroid size. E, Mean shape in red.

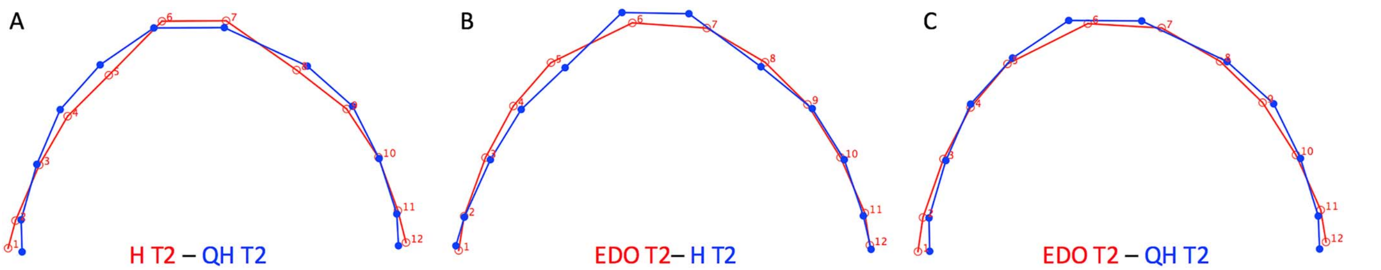

Figure 5. T2 Procrustes mean shape superimpositions. A, H and QHelix. B, H and EDO. C, QH and EDO.

A difference was found in the comparison between QH T1 and EDO T1 dental arch shapes. However, these findings may be related to the premaxilla deviation to the left or right side, a striking feature of BCLP patients,[30] as observed in Figure 4. There was a statistically significant dental arch shape difference between all groups at T2 (Figure 5). However, the intragroup comparison showed no dental arch shape difference between H T1 and H T2, indicating that only the QH and EDO promoted changes in the shape of the dental arch after maxillary expansion (Figure 6). The greater expansion in the anterior region of the maxillary dental arch described by Dalessandri et al.[31] and Tindlund et al.[32] using QH and by Garib et al.[11] using EDO in BCLP patients appeared to be responsible for these shape differences. These changes in dental arch shape are positive for BCLP patients as a result of the triangular morphology of the dental arch described previously.[5]

Another change observed for QH and EDO with shape superimpositions (Figure 6) was the posterior movement of the central incisor, indicating that this posterior movement was enhanced by the greater intercanine expansion. This result was previously reported in cleft[33] and noncleft[34] patients. At the same time that a more parabolic dental arch shape was achieved with greater intercanine expansion using QH and EDO, a Class III interarch relationship can be impaired by the posterior movement of the premaxilla. The sagittal hypoplasia of the midface is already expected in BLCP patients as a side effect of the lip and palate repair.[4]

An interesting difference among groups was the first molar rotation after expansion with the QH, which was not observed in the H and EDO groups (Figure 6). QH anterior extensions were activated against the premolar and canine palatal surfaces, distally rotating the banded molars. The ability to rotate molars with the QH during maxillary expansion was previously reported by Vasant et al.[35]

The orthopedic effect of the maxillary expansion in BCLP patients was expressed as a lateral displacement of the posterior segments, leading to an alignment of these segments with the premaxilla. The maxillary expansion is important to prepare the maxilla to receive the secondary bone graft. The alignment of the maxillary segments, better achieved in the QH and EDO groups (Figure 6), provides lateral walls for performing the alveolar bone graft.[36] Maxillary expansion with the H appliance may lead to posterior overexpansion in order to align the maxillary segments in the cleft area.[10] Further studies will be needed to analyze this clinical effect.

CONCLUSIONS

- H, QH, and EDO promoted similar changes in maxillary dental arch size in patients with bilateral complete cleft lip and palate. H did not produce changes in the maxillary dental arch shape.
- When dental arch shape changes are desired, with greater intercanine than intermolar increase, either the QH or EDO may be used.

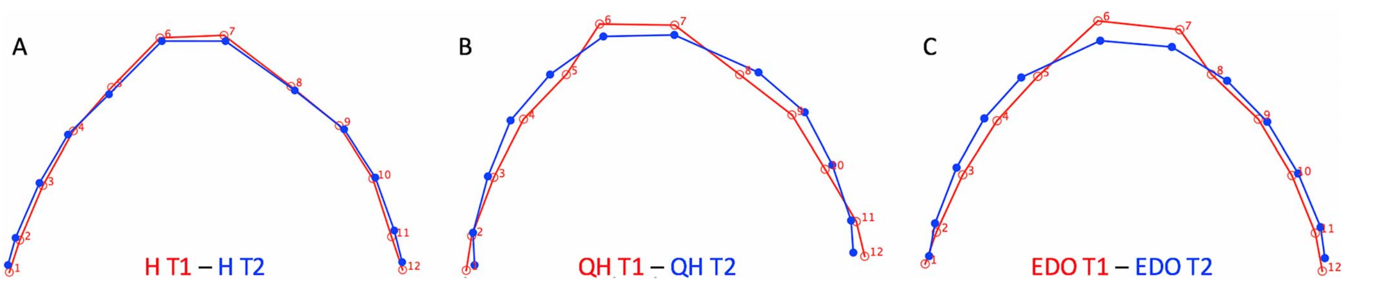

Figure 6. T1 and T2 Procrustes mean shape superimpositions. A, Hyrax. B, Quad-helix. C, Expander with differential opening.

REFERENCES

1. Yáñez-Vico RM, Iglesias-Linares A, Gómez-Mendo I, et al. A descriptive epidemiologic study of cleft lip and palate in Spain. *Oral Surg Oral Med Oral Pathol Oral Radiol*. 2012;114:1–4.
2. Semb G. A study of facial growth in patients with unilateral cleft lip and palate treated by the Oslo CLP Team. *Cleft Palate Craniofac J*. 1991;28:1–21.
3. da Silva Filho OG, de Castro Machado FM, de Andrade AC, de Souza Freitas JA, Bishara SE. Upper dental arch morphology of adult unoperated complete bilateral cleft lip and palate. *Am J Orthod Dentofacial Orthop*. 1998;114:154–161.
4. da Silva Filho OG, Valladares Neto J, Capelloza Filho L, de Souza Freitas JA. Influence of lip repair on craniofacial morphology of patients with complete bilateral cleft lip and palate. *Cleft Palate Craniofac J*. 2003;40:144–153.
5. Heidbuchel KL, Kuijpers-Jagtman AM, Kramer GJ, Prahl-Andersen B. Maxillary arch dimensions in bilateral cleft lip and palate from birth until four years of age in boys. *Cleft Palate Craniofac J*. 1998;35:233–239.
6. Façanha AJ, Lara TS, Garib DG, da Silva Filho OG. Transverse effect of Haas and Hyrax appliances on the upper dental arch in patients with unilateral complete cleft lip and palate: a comparative study. *Dental Press J Orthod*. 2014;19:39–45.
7. Figueiredo DS, Bartolomeo FU, Romualdo CR, et al. Dentoskeletal effects of 3 maxillary expanders in patients with clefts: a cone-beam computed tomography study. *Am J Orthod Dentofacial Orthop*. 2014;146:73–81.
8. de Almeida AM, Ozawa TO, Alves ACM, et al. Slow versus rapid maxillary expansion in bilateral cleft lip and palate: a CBCT randomized clinical trial. *Clin Oral Investig*. 2017;21: 1789–1799.
9. Heidbuchel KL, Kuijpers-Jagtman AM. Maxillary and mandibular dental-arch dimensions and occlusion in bilateral cleft lip and palate patients from 3 to 17 years of age. *Cleft Palate Craniofac J*. 1997;34:21–26.
10. Garib DG, Garcia LC, Pereira V, Lauris RC, Yen S. A rapid maxillary expander with differential opening. *J Clin Orthod*. 2014;48:430–435.
11. Garib D, Lauris RC, Calil LR, et al. Dentoskeletal outcomes of a rapid maxillary expander with differential opening in patients with bilateral cleft lip and palate: a prospective clinical trial. *Am J Orthod Dentofacial Orthop*. 2016;150:564–574.
12. Nie Q, Lin J. A comparison of dental arch forms between Class II Division 1 and normal occlusion assessed by Euclidean distance matrix analysis. *Am J Orthod Dentofacial Orthop*. 2006;129:528–535.
13. Gower JC. Generalized Procrustes Analysis. *Psychometrika*. 1975;40:33–51.
14. Goodall C. Procrustes methods in the statistical analysis of shape. *J R Statist Soc B*. 1991;53:285–339.
15. Singh GD, McNamara JA Jr, Lozanoff S. Procrustes, Euclidean and cephalometric analyses of the morphology of the mandible in human Class III malocclusions. *Arch Oral Biol*. 1998;43:535–543.
16. Cooke SB, Terhune CE. Form, function, and geometric morphometrics. *Anat Rec (Hoboken)*. 2015;298:5–28.
17. Bookstein FL. *Morphometric Tools for Landmark Data: Geometry and Biology*. Cambridge University Press, Cambridge, United Kingdom; 1992.
18. Halazonetis DJ. Morphometrics for cephalometric diagnosis. *Am J Orthod Dentofacial Orthop*. 2004;125:571–581.
19. Wellens HL, Kuijpers-Jagtman AM. Connecting the new with the old: modifying the combined application of Procrustes superimposition and principal component analysis, to allow for comparison with traditional lateral cephalometric variables. *Eur J Orthod*. 2016;38:569–576.
20. Moyers RE, Bookstein FL. The inappropriateness of conventional cephalometrics. *Am J Orthod*. 1979;75:599–617.
21. Bookstein FL. Reconsidering "The inappropriateness of conventional cephalometrics." *Am J Orthod Dentofacial Orthop*. 2016;149:784–797.
22. Klingenberg CP. Size, shape, and form: concepts of allometry in geometric morphometrics. *Dev Genes Evolution*. 2016;226:113–137.
23. Webster M, Sheets AD. A practical introduction to landmark-based geometric morphometrics. *Quant Methods Paleobiol*. 2010;16:163–188.
24. Palomo JM, Hunt DW Jr, Hans MG, Broadbent BH Jr. A longitudinal 3-dimensional size and shape comparison of untreated Class I and Class II subjects. *Am J Orthod Dentofacial Orthop*. 2005;127:584–591.
25. Chatzigianni A, Halazonetis DJ. Geometric morphometric evaluation of cervical vertebrae shape and its relationship to skeletal maturation. *Am J Orthod Dentofacial Orthop*. 2009; 136:481.
26. Singh GD, McNamara JA, Lozanoff S. Finite-element morphometry of soft tissue morphology in subjects with untreated Class III malocclusions. *Angle Orthod*. 1999;69:215–224.
27. Halazonetis DJ. Morphometric evaluation of soft-tissue profile shape. *Am J Orthod Dentofacial Orthop*. 2007;131:481–489.
28. Pavoni C, Paoloni V, Ghislanzoni LTH, Laganà G, Cozza P. Geometric morphometric analysis of the palatal morphology in children with impacted incisors: a three-dimensional evaluation. *Angle Orthod*. 2017;87:404–408.
29. Yu X, Liu B, Pei Y, Xu T. Evaluation of facial attractiveness for patients with malocclusion: a machine-learning technique employing Procrustes. *Angle Orthod*. 2014;84:410–416.
30. Murthy J, Manisha D. Pre-maxillary complex morphology in bilateral cleft and hypothesis on laterality of deviated premaxilla. *Indian J Plast Surg*. 2016;49:336–339.
31. Dalessandri D, Tonni I, Dianiskova S, et al. Rapid palatal expander vs. quad-helix in the orthodontic treatment of cleft lip and palate patients. *Minerva Stomatol*. 2016;65:97–103.
32. Tindlund RS, Rygh P, Olav EB. Intercanine widening and sagittal effect of maxillary transverse expansion in patients with cleft lip and palate during the deciduous and mixed dentitions. *Cleft Palate Craniofac J*. 1993;30:195–207.
33. Ayub PV, Janson G, Gribel BF, Lara TS, Garib DG. Analysis of the maxillary dental arch after rapid maxillary expansion in patients with unilateral complete cleft lip and palate. *Am J Orthod Dentofacial Orthop*. 2016;149:705–715.
34. Habeeb M, Boucher N, Chung CH. Effects of rapid palatal expansion on the sagittal and vertical dimensions of the maxilla: a study on cephalograms derived from cone-beam computed tomography. *Am J Orthod Dentofacial Orthop*. 2013;144:398–403.
35. Vasant MR, Menon S, Kannan S. Maxillary expansion in cleft lip and palate using Quad Helix and rapid palatal expansion screw. *Med J Armed Forces India*. 2009;65:150–153.
36. Freitas JA, Garib DG, Oliveira M, et al. Rehabilitative treatment of cleft lip and palate: experience of the Hospital for Rehabilitation of Craniofacial Anomalies-USP (HRAC-USP)—part 2: pediatric dentistry and orthodontics. *J Appl Oral Sci*. 2012;20:268–281.