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RESEARCH ARTICLE

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Evaluation of palate morphology in patients treated with leaf expander and hyrax expander: A geometric morphometric analysis

Francesca Silvestrini-Biavati[1] | Giorgio Oliva[2] | Luis Huanca Ghislanzoni[3] | Elisa Ottonelli[1] | Domenico Dalessandri[4] | Valentina Lanteri[5] | Alessandro Ugolini[1]

[1]Department of Surgical Sciences and Integrated Diagnostics, University of Genoa, Genoa, Italy

[2]Section of Orthodontics, Department of Neuroscience, Reproductive Sciences and Oral Sciences, University of Naples Federico II, Naples, Italy

[3]Department of Orthodontic, Université de Genève, Geneva, Switzerland

[4]Department of Orthodontics, University of Brescia, Brescia, Italy

[5]Surgical, Medical, and Dental Department, University of Modena and Reggio Emilia, Modena, Italy

Correspondence
Valentina Lanteri, Surgical, Medical, and Dental Department, University of Modena and Reggio Emilia, Via del Pozzo, 71 – 41124 Modena, Italy.
Email: valentina.lanteri@unimore.it

Abstract

Objective: The aim of this study was to evaluate changes in shape of the palatal vault after maxillary expansion with hyrax expander (HE) and leaf expander (LE), using 3D Geometric Morphometric Analysis.

Setting and Sample Population: Overall, 250 patients (110 M, 140 F) with maxillary transverse deficiency were selected for this study. In this study, 127 subjects were treated with HE, 123 with LE.

Materials and Methods: Digital dental models were obtained pre-treatment (T0) and after 12 months from the cementation of the device (T1) and processed by means of a digital scanner. Linear and morphometric analyses were conducted to determine the effects of each appliance on dental measurements and palatal shape, and a multiple linear regression was performed to analyse the influence of anchorage and appliance type on final shape.

Results: Morphometric analysis showed that there was a lowering of the palatal vault in the HE group, while in the LE group it remained unchanged: the difference in palatal shape at time T0 and T1 was statistically significant in both treatments (HE vs. LE). In the HE group, the change in shape also included the upper part of the palatal vault in the vertical dimension, while in the LE group the change in shape interested mainly palatal shelves and the lower portion of the palate.

Conclusions: Both LE and HE produce clinically significant changes in the morphology of the palatal vault.

KEYWORDS
geometric morphometric analysis, malocclusion, orthodontics, palatal expansion, transverse deficiency

1 | INTRODUCTION

Transverse discrepancy between maxillary and mandibular arches often produces posterior crossbite, representing one of the most frequent malocclusions in mixed dentition with a prevalence of 7%–23%.[1,2]

When it occurs unilaterally, posterior crossbite shows a functional shift of the mandible towards the crossbite side, due to a maxillary constriction which leads to teeth interferences in maximum intercuspation: in this situation, molar relationship will be asymmetric, with a Class II on the crossbite side and a Class I or a Class III on the opposite side, and a consequent shift of the inferior midline to the side of the crossbite.[3] Shift can lead to the development of craniofacial asymmetries in adulthood if not treated early.[4,5]

Systematic reviews have demonstrated that Rapid Maxillary Expansion (RME) is a useful and consolidated technique to correct maxillary transverse deficiency,[4,6] because it eliminates occlusal interferences and allows a harmonic growth of skeletal structures.[3]

Also, Slow Maxillary Expansion (SME) can be used in growing patients.[7] While with RME there is an immediate midpalatal suture separation, due to heavy and intermittent forces used for a short time, SME is obtained by using lower forces for a longer time,[8] with different slow protocols depending on the type of device used.

According to the literature, RME seems to represent the most validated and consolidated treatment for posterior crossbite, because it not only maximizes skeletal effects[9] but also it can have many possible side effects like relapse of the expansion, tipping of the molar axes, bone loss and root resorption.[7,10–12]

On the contrary, SME has been revaluated because it produces a graduate sutural separation, reducing post-expansion relapse and allowing greater stability.[13]

Similar to SME protocol, leaf expander is a new device characterized by a double nickel titanium leaf spring in addition to a midline jackscrew: the screw is preactivated in laboratory and generate 3 mm of expansion, then the orthodontist can activate it by compressing the leaf springs, generating a constant force (450 or 900 g based on the screw chosen and the clinician's decision) and avoiding patient's compliance. Moreover, the pain perceived during the expansion seems to be lower, because the design of the leaf screw allows a slow and continuous activation, reducing the forces transmitted to the sutural complex and the consequent inflammatory process.[14,15] Previous studies have demonstrated that leaf expander creates less discomfort for the patient and less pain during the first days of activation, and it allows also a better oral hygiene.[14] Furthermore, many recent studies have demonstrated that RME and leaf expander result in similar clinical outcomes.[16–18]

Many previous studies have been carried on referring to linear or angular measurements to investigate the effects of both RME and SME on the maxillary complex,[4,19] using plaster and digital models[20,21] or radiographies like occlusal,[20] laterolateral[22] and posteroanterior[23]: all these data sets rely on the two dimensions of the space and require research to analyse many measurements at the same time to have a right interpretation of morphological changes.

Nowadays, the development of technology has introduced new possibilities of analyses in the three spatial dimensions: digital models and CBCT imaging[24] permit to obtain three-dimensional images of craniofacial skeleton, allowing clinicians to evaluate better orthodontic treatment using 3D geometric morphometric analysis (GMA).[25,26]

This analysis allows one to directly visualize shape changes as images, with illustrations that regard morphological differences in their anatomical context[4]; in this way, GMA can be considered a useful tool also applied in orthodontics and to describe shape variation between individuals.

In most studies in the literature, changes in the dental arches and skeletal expansion are analysed and a little relevance is given to 3D changes in the palate with a morphological approach. Instead, it is very important to evaluate the changes in palatal shape, especially in relation to the functional aspect of the tongue and the functions in which it is involved (swallowing, phonation, chewing, breathing).

Only a few studies have analysed morphological changes in the maxilla after expansion[27] as assessed by GMA.[4,25]

The aim of this study was to evaluate changes of the shape of the palatal vault after expansion comparing patients with intermaxillary discrepancy treated with hyrax type expander (HE) with those treated with leaf expander, using 3D morphometric analysis and GMA approach in order to illustrate with a morphological method the differences in palatal shape between the two devices.

2 | MATERIALS AND METHODS

This is a retrospective study, and it evaluates digital dental casts of growing patients orthodontically treated before and after treatment. The sample was collected using the database of the Department of Orthodontics, University of Genoa and in collaboration with the University of Milan and University of Brescia. The study was conducted in agreement with the Helsinki declaration (version, 2008). Ethics Committee University of Milan n. 51/21. The parents or the legal guardians of each subject of the sample had to accept an informed written consent before the beginning of dental treatment.

The study included 250 patients, both males (110) and females (140), all with maxillary transverse deficiency, divided into two groups:

- HE group, consisting of 127 patients treated with hyrax type expander with rapid protocol;
- LE group, consisting of 123 patients treated with leaf expander.

There is no consensus in the literature on the methods for calculating sample sizes for morphometric studies. Cardini et al.[28] in a recent and voluminous study demonstrated the validity of calculating average shapes even with small samples. Farnell[29] has also emphasized the fundamental importance of having balanced groups when using PCA analyses with multiple groups. Based on these considerations and a previously published pilot study,[4] we believe that our sample may be representative.

Sample was selected following some inclusion criteria:

- Early or intermediate mixed dentition – Stage 2 according to Bjork classification with incisors fully erupted[30];
- First molars fully erupted, both primary and second deciduous molars preserved;
- CSV 1–3;
- Angle Class I or II malocclusion (as defined by Proffit[31]);
- Unilateral or bilateral posterior crossbite and maxillary constriction (intermolar width < 30 mm);

- Crowding in the upper arch;
- No previous orthodontic treatments.

Subjects with craniofacial abnormalities, Angle Class III malocclusion, TMJ disorders, previous extraction or surgical treatments, untreated caries on second deciduous molars or incomplete or wrong scan and documentation were excluded.

Both hyrax expander and leaf expander were anchored either on the second deciduous molars (164) or on the first permanent molars (86), with an anterior arm up to the canines and a screw of 6 mm – 450 g. Hyrax expander was activated twice a day, with 0.2 mm of expansion for each activation; leaf expander was instead preactivated of 3 mm in laboratory, then is activated with 10 turns after 10 weeks, other 10 turns after 4 weeks and other 10 turns after 4 weeks.[32] At the end of the activations, both the two devices were left in situ and removed after a period of 9–11 months, according to the clinical needs. The expansion was clinically reached in all the subjects treated, even if the specific amount of expansion in each single case was not evaluated.

Digital dental models were obtained pre-treatment (T0) and after 12 months from the cementation of the device (T1) and processed by means of an intraoral scanner: 3Shape D250 (3Shape, Copenhagen, Denmark); the appliances have been removed before running the second scan.

The validity and precision of the scanner are both of ±0.05 mm.

2.1 | Linear analyses

The following distances were used for the linear analyses:

- Cuspids: linear distance between apexes of maxillary deciduous cuspids.
- 1° bicuspids: linear distance between apexes of vestibular cusp of permanent first bicuspids or mesio-vestibular cusp of first deciduous molars.
- 2° bicuspids: linear distance between apexes of vestibular cusp of permanent second bicuspids or mesio-vestibular cusp of second deciduous molars.
- Molar linear: distance between apexes of vestibular cusp of permanent first molar.
- Arch rise: trigonometric distance of the midpoint between the two medial points of the central incisors and a straight line passing through the two mesial points of the first upper molars.
- Perimeter: sum of 5 linear distances: distal margin of first right molar to distal margin of right cuspid, distal margin of right cuspid to distal margin of right first incisor, distal margin of right first incisor to distal margin of left first incisor, distal margin of left first incisor to distal margin of left cuspid, distal margin of left cuspid to distal margin of left first molar.

All analyses were conducted on the ‘differences’ at time T1 and T0 identified in each patient (delta = d). The differences between the two devices were tested using Student's *t*-test on all identified measurements. The differences introduced by each appliance in transverse diameters were tested by comparing the effect on molars with that on canines and second deciduous molars (Student's *t*-test).

To establish the influence of the type of anchorage, a multiple linear regression was performed as follows:

$$\text{d-molar} = \text{d-cuspid} + \text{AppType} + \text{Anchorage}.$$

2.2 | Morphometric analysis

The analysis of the three-dimensional images of the palates was carried out using Viewbox software (Dhal Software). Some landmarks were inserted to define the perimeter of the palatal vault (12 landmarks), the posterior perimeter (three landmarks) and the midline (two landmarks). The surface of the palate was studied by applying 222 semilandmarks on the palatal vault. A total of 239 points were analysed.

After performing the generalized procrustes superimposition (GPS)[33] with all subjects involved in the study, the mean of four subgroups was calculated: patients treated with hyrax expander (HE) at time 0 (HE-T0), patients treated with HE at time T1 (HE-T1), patients treated with leaf expander (LE) at time T0 (LE-T0), and patients treated with LE at time T1 (LE-T1).

A between-group principal component analysis (bg-PCA) was performed to compare the four groups. Goodall's *F*-test was used to test the difference between time T0 and T1 in the two treatments.

A multiple linear regression was performed to analyse the influence of anchorage and appliance type on the final shape. As the dependent variable, the coordinates of all palates at T1 were used after a new GPS. As independent variables, the variables ‘anchorage and type of treatment’ and the variables ‘sex and cuspidT0’ were added as possible confounders. The regression thus resulted in:

$$\text{T1-Coord} = \text{anchorage type} + \text{treatment type} + \text{sex} + \text{cuspidT0}.$$

3 | RESULTS

3.1 | Linear analyses

Table 1 shows the differences due to the two types of treatment. The variables molar, premolar and canine diameter were compared at T0 and no significant differences were found. The only measure found to be statistically different is the height of the palatal vault: while in LE patients it remains unchanged, in HE patients there is a lowering of the palatal vault.

With regard to the changes introduced by the individual devices (Table 2) in the HE group, there were no differences between the expansion obtained on the molars and that obtained on the canines or second deciduous molars. In the LE group, the expansion obtained on molars is significantly greater than that obtained on second deciduous molars, but not greater than that obtained on canines. However, molars and canines are two anchor points of both the devices.

TABLE 1 The differences between T0 and T1 of linear distances analysed. The two appliances have been compared with *t*-test. The *p*-values of the tests are reported in this table.

Variables	Hyrax expander		Leaf expander		
	Mean	SE	Mean	SE	*p*-Value
Cuspids	4.09	0.22	4.06	0.25	.92
1° bicuspid	4.70	0.22	4.57	0.26	.71
2° bicuspid	4.93	0.22	4.41	0.26	.13
First molar	4.13	0.37	3.49	0.26	.16
Arch rise	−0.33	0.32	0.51	0.16	.02*
Perimeter	3.50	0.83	3.92	0.34	.64

*$p < .05$.

TABLE 2 Differences between molar expansions and other linear measurements analysed. A *t*-test has been conducted to test the significance of the differences. The *p*-values of the tests are reported in this table.

Variables compared to 'molar'	Hyrax expander		Leaf expander	
	Mean difference	*p*-Value	Mean difference	*p*-Value
Cuspids	0.04	.93	−0.61	.10
1° bicuspids	−0.57	.18	−1.09	.01*
2° bicuspids	−0.80	.07	−0.92	.01*

*$p < .05$.

The results of the multiple linear regression (Table 3) show that for the same expansion (d-cuspid), neither the type of equipment nor the type of anchorage changes the amount of expansion obtained on the molars.

3.2 | Morphometric analysis

Figure 1 shows in comparison the mean shapes of the four groups after superposition. Figure 2 shows the bg-PCA results. In the HE group, the difference between time T0 and T1 consists of a change in shape described by both Principal Component 1 (PC1) and Principal Component 2 (PC2). The differences described by PC2 are not present in patients treated with the leaf expander; instead, the differences described by PC1 are present, although in smaller quantities compared to the hyrax expander. In particular, PC1 describes changes in the lower portion of the palate and in the palatal shelves in a transverse direction and in the anterior portion of the palate in a sagittal direction. PC2 shows a change in shape including mainly the upper part of the palatal vault and in the vertical dimension.

The difference in shapes at time T0 and T1 is statistically significant for both treatments (Goodall's *F*-test less than 0.05).

Table 4 shows the results of the multiple linear model. Although sex and cuspidT0 were reported as possible confounders, sex was

TABLE 3 Results from multilinear regression. The dependent variable is the degree of expansion at molars. Independent variables were degree of expansion at cuspids, type of anchorage and type of treatment.

Ind. variables	Coef.	SE	*F*	P > (*F*)
Cuspids	0.48	0.08	5.92	0.01
Anchorage	0.05	0.47	0.11	0.9
Treatment	−0.65	0.44	0.14	0.14
Residuals	2.11	0.49		

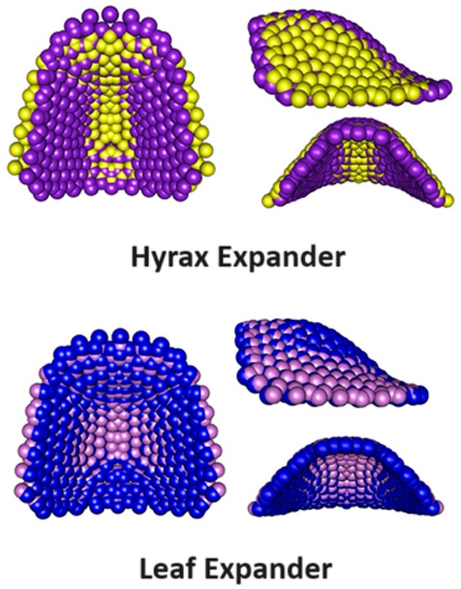

FIGURE 1 Comparison between the average forms of the four groups after the procrustean superimposition: HE-T0 in violet, HE-T1 in yellow, LE-T0 in blue and LE-T1 in pink.

not statistically significant. On the other hand, the relationships between anchorage type and shape at time T1 and the type of treatment chosen were statistically significant.

4 | DISCUSSION

The correction of maxillary contraction has been reached in all patients both in the HE group and in the LE group, and the two treatments seemed to be equally effective in the resolution of maxillary transverse deficiency, as reported in the literature. In fact, the two appliances do not show significant differences from a clinical point of view,[16,17] if we observe their effects on maxillary expansion, even if they work differently: HE is characterized by a jack screw, the activation of which generates an intermittent and heavy force necessary to open the midpalatal suture, while LE has two or more leaf springs in nickel titanium which return to their original form during deactivation, producing a calibrate expansion of the upper arch and generating light and constant forces.[32]

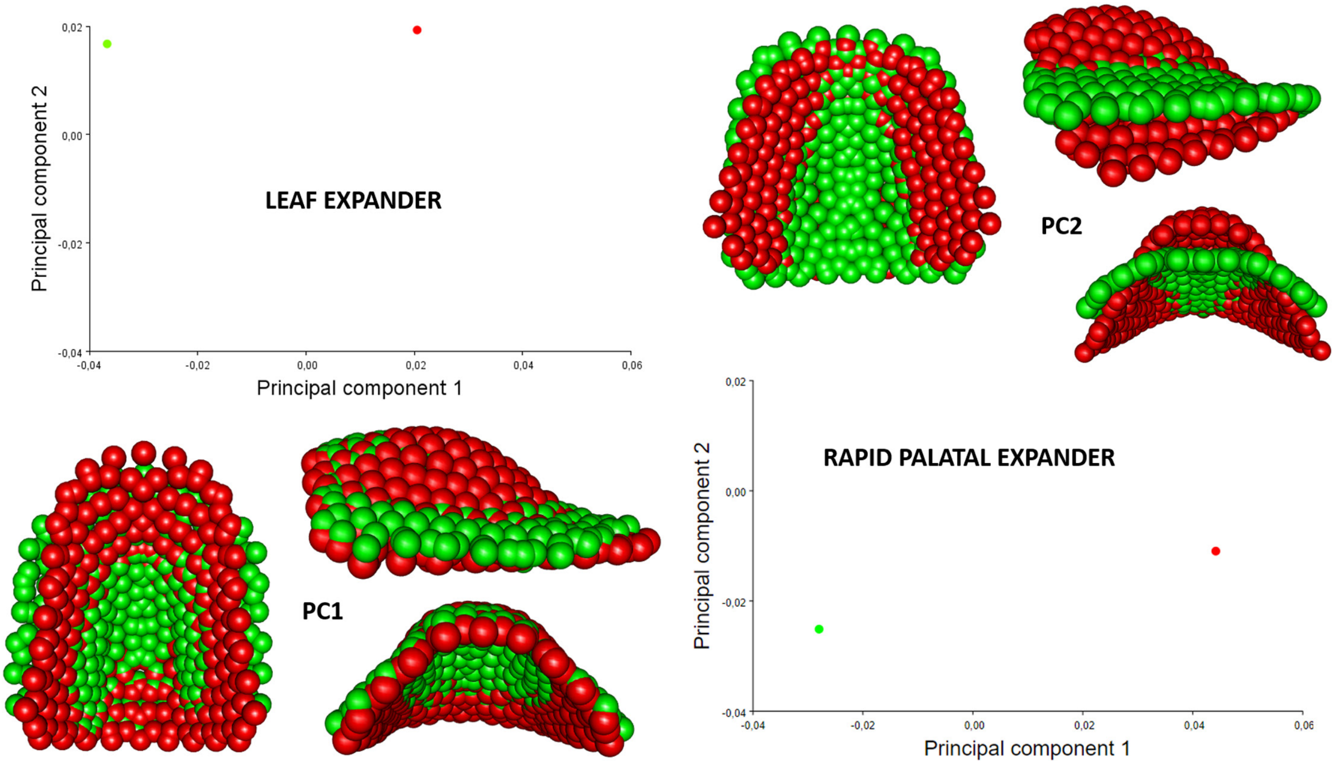

FIGURE 2 The PC1 describes changes in the lower portion of the palate and in the palatal shelves in the transverse sense and in the anterior portion in the sagittal sense. The PC2 shows a change in shape that mainly affects the upper part of the palatal vault and the vertical dimension. The red dots refer to the shape before treatment, the green dots refer to the shape after treatment.

TABLE 4 Results from the multiple linear regression. The dependent variables are palatal vault shapes at T1. Anchorage is a two-parameter factor (second deciduous molar or first permanent molar). Sex is a two-parameter factor (male or female). Treatment is a two-parameter factor (hyrax expander or leaf expander). CuspidT0 is a numerical continuous variable (Cuspids distance at T0).

Ind. variables	Mean squares	*F*	Pr(>*F*)
Anchorage	0.02	2.69	0.01
Sex	0.005	0.70	0.65
Treatment	0.105	13.97	<0.01
CuspidT0	0.04	3.30	0.01
Res.	0.0076		

According to the previous study,[27] this research demonstrates that palatal form difference T0-T1 in both HE and LE groups is statistically significant (Goodall's F-test <0.05), so both the two appliances are effective treatments for maxillary expansion,[34] and both modify palatal morphology (Figure 1).

The morphometric analysis has shown these results: in the HE group, the change in shape is described by both Principal Component 1 (PC1) and Principal Component 2 (PC2), where PC1 describes changes in the palatal shelves and in the lower portion of the palate in a transverse direction and in the anterior portion in a sagittal direction, while PC2 describes mainly the vertical dimension of the palatal vault (Figure 2).

Transversal changes are significant both in the HE group and in the LE group, as indicated by PC1, while vertical changes are significant only in the HE group (PC2).

With regard to the differences of linear analysis (intermolar distance, intercanine distance, inter-first and second deciduous molars distance, perimeter of the arch and arch depth in the sagittal sense) due to the two types of treatment, the only measure found to be statistically different is the arch rise.

As many previous studies[4,25,35] have already demonstrated, morphometric analysis seems to be a useful research tool to evaluate fields that normally can't be observed using linear traditional analysis: the major effect of expansion treatment on the palate morphology determines a significant transversal expansion with a lowering of the palatal vault, with a consequent increased functional space for the tongue.

Hyrax expander has more efficacy to determine a vertical remodelling of the palatal vault but there is no significant difference on the amount of expansion reached: the protocols analysed have produced the same mean amount of expansion on molars, deciduous molars and canines.[36]

According to the literature, the two devices work in a superimposable way despite the difference in activation.[16,17,32] The clinical differences in the results are minimal and it appears that the major differences are not due to the activation protocol but to the anchoring factor, which will be the subject of future investigation.

The relationships between anchorage type and shape at time T1 and the type of treatment chosen were statistically significant ($p < .01$), while gender is not significant ($p = .65$).

This is confirmed by a precedent study[37] that suggests that the anchorage on second deciduous molars determines a more effective skeletal expansion with less dentoalveolar compensation, producing a greater effect on palatal vault than the anchorage on first molars, both in the HE and in the LE group. Consequently, there is a major and more stable expansion in the anterior zone of the palatal vault, despite of an anchorage on first molars, in which the increased angulation of the elements 1.6 and 2.6 shows a more dentoalveolar compensation: this finding is supported by other studies that examined both dental[38] and tooth-bone[10] anchored devices, which demonstrated more substantial expansion in the anterior area of the palate and a distal rotation of the maxillary first molars, likely due to the varied placement of the screw.[39]

With regard to the different types of anchorage, this study has shown that no differences have been observed between the expansion obtained on the molars and that obtained on the canines, both in the HE and LE groups. The expansion obtained with the anchorage on first molars seems to be apparently greater than that obtained when the anchorage was on second deciduous molars, this because there is more dental compensation due to dental displacement following the hypothetical loss of anchorage; however, the anchorage on first molars determines less effect on the palatal vault, as previously reported.

The multiple linear regression shows that neither the type of appliance nor the type of anchorage has changed the amount of expansion obtained on the molars: using the anchorage as a confounder, the two types of treatment are equally effective, and they have a statistically significant influence on the final shape of the palate.

A linear analysis focused explicitly on the type of the anchorage of the device used could be useful to better understand this topic in future studies, and to visualize the differences in shape of palatal vault after the two treatments. This represents one of the limits of our study, in addition to its retrospective structure.

5 | CONCLUSIONS

The conclusions of this study can be described as follows:

- The difference in palatal shape at time T0 and T1 is statistically significant in both treatment (hyrax expander vs. leaf expander) according to morphometric analysis: in the hyrax expander group, the change in shape also include the upper part of the palatal vault in the vertical dimension, while in leaf expander group the change in shape interests mainly palatal shelves and the lower portion of the palate.
- Appliances anchored on first molars determine less effect on the palatal vault. The second deciduous molars have proven to be a more effective anchorage in relation to changes in the palatal vault.
- Both hyrax expander and leaf expander improve the morphology of the palate, clinically resulting in an improvement in the functional space for the tongue.

Based on the data presented, the choice of which type of appliance is better to use is still linked to the orthodontist's experience,[32] depending on what goals the clinician wants to achieve, and it should be evaluated on the single patient, in order to choose a device able not only to reach a good expansion but also based on other important variables for the success of an effective, efficient and appropriate treatment: the need for patient or parents' compliance, the discomfort perceived and the difficulties in maintaining a good oral hygiene.

AUTHOR CONTRIBUTIONS

Giorgio Oliva was involved in conceptualization, methodology, investigation, wrote the original drafted manuscript. Luis Huanca Ghislanzoni was involved in data curation, software and conceptualization. Elisa Ottonelli was involved in investigation, data curation and project administration. Valentina Lanteri was involved in visualization, conceptualization, investigation and data curation. Domenico Dalessandri was involved in visualization, investigation and supervision. Alessandro Ugolini was involved in conceptualization, supervision and wrote, reviewed and edited the manuscript. Francesca Silvestrini-Biavati was involved in supervision, wrote, reviewed and edited the manuscript.

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Nothing to declare.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

The study was conducted in agreement with the Helsinki declaration (version, 2008). Ethics Committee University of Milan n. 51/21.

CONSENT TO PARTICIPATE

The parents or the legal guardians of each subject of the sample had to accept an informed written consent before the beginning of dental treatment.

ORCID

Francesca Silvestrini-Biavati https://orcid.org/0000-0003-2899-8450
Domenico Dalessandri https://orcid.org/0000-0002-9020-7843
Valentina Lanteri https://orcid.org/0000-0003-2191-8673
Alessandro Ugolini https://orcid.org/0000-0002-2062-6014

REFERENCES

1. Leonardi R, Lo Giudice A, Rugeri M, Muraglie S, Cordasco G, Barbato E. Three-dimensional evaluation on digital casts of maxillary palatal size and morphology in patients with functional posterior crossbite. *Eur J Orthod*. 2018;40(5):556-562.
2. Da Silva Filho OG, Santamaria M Jr, Capelozza FL. Epidemiology of posterior crossbite in the primary dentition. *J Clin Paediatr Dent*. 2007;32:73-78.
3. Bukhari A, Kennedy D, Hannam A, Aleksejuniene J, Yen E. Dimensional changes in the palate associated with slow maxillary expansion for early treatment of posterior crossbite. *Angle Orthod*. 2018;88(4):390-396.
4. Oliva G, Huanca Ghislanzoni L, Dalessandri D, Silvestrini-Biavati A, Ugolini A. Palatal changes in crossbite patients treated with rapid maxillary expansion vs untreated ones: a geometric morphometric study. *Orthod Craniofacial Res*. 2020;23:439-444.
5. Tsanidis N, Antonarakis GS, Kiliaridis S. Functional changes after early treatment of unilateral posterior cross-bite associated with mandibular shift: a sistematic review. *J Oral Rehabil*. 2016;43:59-68.
6. Ugolini A, Agostino P, Silvestrini-Biavati A, Harrison JE, Batista KB. Orthodontic treatment for posterior crossbites. *Cochrane Database Syst Rev*. 2021;12(12):CD000979.
7. Martina R, Cioffi I, Farella M, et al. Transverse changes determined by rapid and slow maxillary expansion – a low dose CT-based randomized controlled trial. *Orthod Craniofacial Res*. 2012;15:159-168.
8. Ulema RGL, Jacob HB, Brunetto M, Juliana P, da Silva TOM, Buschang PH. A preliminary 3-D comparison of rapid and slow maxillary expansion in children: a randomized clinical trial. *Int J Paediatr Dent*. 2020;30:349-359.
9. Haas AJ. Palatal expansion: just the beginning of dentofacial orthopedics. *Am J Orthod*. 1970;57:219-255.
10. Drago S, Campobasso A, Battista G, De Mari A, Menini M, Migliorati M. Torque changes of anchorage units in pre-adolescent patients treated with a digitally designed tooth-borne expander anchored to deciduous vs. permanent molars. *Eur J Paediatr Dent*. 2023;24(4):297-303.
11. Lemons Rinaldi MR, Azeredo F, Martinelli de Lima E, Deon Rizzatto SM, Sameshima G, Macedo de Menezes L. Cone beam computed tomography evaluation of bone plate and root length after maxillary expansion using tooth-borne and tooth-tissue-borne banded expanders. *Am J Orthod Dentofacial Orthop*. 2018;154:504-516.
12. Akyalcin S, Alexander SP, Silva RM, English JD. Evaluation of three-dimensional root surface changes and resorption following rapid maxillary expansion: a cone beam computed tomography investigation. *Orthod Craniofacial Res*. 2015;18(Suppl 1):117-126.
13. Costa JG, Galindo TM, Mattos CT, Cury-Saramago AA. Retention period after treatment of posterior crossbite with maxillary expansion: a systematic review. *Dental Press J Orthod*. 2017;22(2):35-44.
14. Ugolini A, Cossellu G, Farronato M, Silvestrini-Biavati A, Lanteri V. A multicenter, prospective, randomized trial of pain and discomfort during maxillary expansion: leaf expander versus hyrax expander. *Int J Paediatr Dent*. 2020;30(4):421-428.
15. Lanteri C, Beretta M, Lanteri V, Gianolio A, Cherchi C, Franchi L. The leaf expander for non-compliance treatment in the mixed dentition. *J Clin Orthod*. 2016;50(9):552-560.
16. Abate A, Ugolini A, Maspero C, Silvestrini-Biavati F, Caprioglio A, Lanteri V. Comparison of the skeletal, dentoalveolar, and periodontal changes after Ni-Ti leaf spring expander and rapid maxillary expansion: a three-dimensional CBCT based evaluation. *Clin Oral Investig*. 2023;27(9):5249-5262.
17. Paoloni V, Giuntini V, Lione R, et al. Comparison of the dento-skeletal effects produced by leaf expander versus rapid maxillary expander in prepubertal patients: a two-center randomized controlled trial. *Eur J Orthod*. 2022;44(2):163-169.
18. Maschio M, Gaffuri F, Ugolini A, Lanteri V, Abate A, Caprioglio A. Buccal alveolar bone changes and upper first molar displacement after maxillary expansion with RME, Ni-Ti leaf springs expander and tooth- bone-borne expander. A CBCT based analysis. *Eur J Paediatr Dent*. 2023;24(3):211-215.
19. Lagravère MO, Heo G, Major PW, Flores-Mir C. Meta-analysis of immediate changes with rapid maxillary expansion treatment. *J Am Dent Assoc*. 2006;137:44-53.
20. Gracco A, Malaguti A, Lombardo L, Mazzoli A, Raffaeli R. Palatal volume following rapid maxillary expansion in mixed dentition. *Angle Orthod*. 2010;80(1):153-159.
21. Lanteri V, Cossellu G, Farronato M, et al. Assessment of the stability of the palatal rugae in a 3D-3D superimposition technique following slow maxillary expansion (SME). *Sci Rep*. 2020;10(1):2676.
22. Chung C, Font B. Skeletal and dental changes in the sagittal, vertical, and transverse dimensions after rapid palatal expansion. *Am J Orthod Dentofacial Orthop*. 2004;126:569-575.
23. Cross D, McDonald J. Effect of rapid maxillary expansion on skeletal, dental and nasal structures: a postero-anterior cephalometric study. *Eur J Orthod*. 2000;22:519-528.
24. Garrett BJ, Caruso JM, Rungcharassaeng K, Farrage JR, Kim JS, Taylor GD. Skeletal effects to the maxilla after rapid maxillary expansion assessed with cone-beam computed tomography. *Am J Orthod Dentofacial Orthop*. 2008;134:8-9.
25. Huanca Ghislanzoni L, Lione R, Cozza P, Franchi L. Measuring 3D shape in orthodontics through geometric morphometrics. *Progr Orthod*. 2017;18:38.
26. Pavoni C, Paoloni V, Ghislanzoni LH, Laganà G, Cozza P. Geometric morphometric analysis of the palatal morphology in children with impacted incisors: a three-dimensional evaluation. *Angle Orthod*. 2017;87(3):404-408.
27. Lione R, Pavoni C, Laganà G, Ottria L, Cozza P. Rapid maxillary expansion: effects on palatal area investigated by computed tomography in growing subjects. *Eur J Paediatr Dent*. 2012;13(3):215-218.
28. Cardini A, Elton S, Kovarovic K, Vidarsdòttir US, Polly PD. On the misidentification of species: sampling error in primates and other mammals using geometric morphometrics in more than 4000 individuals. *Evol Biol*. 2021;48:190-220.
29. Farnell Damian JJ. An exploration of pathologies of multilevel principal components analysis in statistical models of shape. *J Imaging*. 2022;8(3):63.
30. Björk A, Krebs A, Solow B. A method for epidemiological registration of malocculusion. *Acta Odontol Scand*. 1964;22:27-41.
31. Proffit WR, Fields HW Jr. *Ortodonzia Moderna*. Masson; 1995:82-83.
32. Lanteri V, Cossellu G, Gianolio A, et al. Comparison between RME, SME and leaf expander in growing patients: a retrospective posterio-anterior cephalometric study. *Eur J Paediatr Dent*. 2018;19(3):199-204.
33. Klingenberg CP. Walking on Kendall's shape space: understanding shape spaces and their coordinate systems. *Evol Biol*. 2020;47(4):334-352.
34. Lanteri V, Abate A, Cavagnetto D, et al. Cephalometric changes following maxillary expansion with Ni-Ti leaf springs palatal expander and rapid maxillary expander: a retrospective study. *Appl Sci*. 2021;11(12):5748.
35. Huanca Ghislanzoni L, Leemann B, Christou P, Muller F, Schimmel M, Kiliaridis S. Palatal morphology changes in post-stroke patients measured by geometric morphometrics. *J Oral Rehabil*. 2017;44(3):172-177.
36. Lanteri V, Gianolio A, Gualandi G, Beretta M. Maxillary tridimensional changes after slow expansion with leaf expander in a sample of growing patients: a pilot study. *Eur J Paediatr Dent*. 2018;19(1):29-34.
37. Ugolini A, Cerruto C, Di Vece L, et al. Dental arch response to Haas – type rapid maxillary expansion anchored to deciduous vs

permanent molars: a multicentric randomized controlled trial. *Angle Orthod*. 2015;85(4):570-576.
38. Cerruto C, Ugolini A, Di Vece L, Doldo T, Caprioglio A, Silvestrini BA. Cephalometric and dental arch changes to Haas-type rapid maxillary expander anchored to deciduous vs pemanent molars: a multicenter, randomized controlled trial. *J Orofac Orthop*. 2017;78:385-393.
39. de Sousa M, Araugio R, Landre J Jr, et al. Influence of the expansion screw height on the dental effects of the hyrax expander: a study with finite elements. *Am J Orthod Dentofacial Orthop*. 2013;143(2):221-227.

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