Craniofacial Morphology and Knowledge of the Stability in Class III Malocclusion Growing Subjects

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Abstract: *Introduction*: to investigate the palatal and craniofacial relationship in Class III growing patients between successful and failed treated groups.

Methods: Thirty-one patients treated with RME/FM/BB were enrolled (inclusion criteria: Caucasian ancestry, III Class malocclusion, maturation stage CS1-CS2, mixed dentition). Digital cast and cephalometric analysis were performed on pre-treatment and post-treatment records. Statistical analysis and a discriminant analysis was performed. GMM was used on digital dental casts with Procrustes analysis to assess the covariation between palatal and craniofacial morphology. Two groups (relapse, R, 19 and success S, 12) were identified.

Results: R group showed a greater maxillary-anterior transversal width at T0. At T1 R showed a shorter maxillary-anterior length than S. A larger maxillary-anterior and posterior-transversal widths was found in both groups. S had greater maxillary-anterior and posterior-sagittal length. A larger mandibular-anterior and posterior-transversal widths was shown in R, while S showed no differences in mandibula. Maxillary-anterior and maxillary-posterior length were two predictive variables found by discriminant analysis. The PC1 showed significant changes in the palatal morphology and revealed differences for the craniofacial vertical components. Palatal and craniofacial shapes showed a significant covariation, linking the palatal width to skeletal divergence.

Discussion: In Class III malocclusion increases in vertical divergence are correlated with a higher palatal vault and narrower width. A wider and shorter maxillary morphology could be a relapse factor for Class III orthopedic treatment, while the lack of mandibular modification could be predisposing for treatment success.

Keywords: Class III malocclusion, Early Orthopedic Treatment, GMM Analysis, Digital Casts Analysis.

INTRODUCTION

The morphology of dental and skeletal characteristics of a Class III malocclusion have been largely investigated on lateral cephalograms and dental casts. Among Class III malocclusion patients, a reduced percentage (less than 20%) showed pure mandibular prognathism, 25% of patients showed only a retrognathic maxilla, while 22% of patients presented with both these two components [1]. A protruded mandible and a retruded maxilla, with a longer inferior facial height, proclination of maxillary incisors and retroclined mandibular incisors were the variables most frequently seen [2]. Cephalometric investigations also revealed that these patients showed a forward glenoid fossa, a shorter cranic base and a large gonial angle [3, 4] The etiology of Class III malocclusion is a result of genetic and environmental factors that affect its development [5]. In order to control this malocclusion, the scientific community recommend starting the Class III malocclusion treatment as soon as possible during the early maturation development [6]. The literature has provided evidence that Class III growth patterns oppose long-term stability. In fact, in Class III the growth spurt lasts longer if compared to Class I and Class II [7]. A long-term good prognosis is guaranteed by a positive maxillary treatment response to the forward traction, but also by the mandibular amount and direction of growth during pubertal spurt [5-7]. Stability Class III malocclusion has been further investigated. Tweed found out two Class III stability patterns. The first one was a good responder pattern, characterized by a standard size of mandibula and a short and narrow maxilla, a decreased divergence, and a normal gonial angle. The second one, the bad responder pattern, had a protruded mandibula of large dimensions and a narrow maxilla, an open gonial angle, and showed an increased divergence [8]. Other authors investigated predictive stability variables through cephalometric analysis. Stability factors most frequently observed were: Gonial angle, SNB angle, Wits appraisal, Ramus length, Mandibular plane angle, Lower incisor inclination, and CondAx-SBL [9-15]. Conventional cephalometry and traditional dental cast analysis have been implemented by the digital three-dimensional analysis [16, 17]. In particular, Geometric morphometric analysis (GMM) is a three-dimensional

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method that investigates skeletal and dental morphology in order to analyze the differences more efficiently than traditional methods [18]. GMM also analyzes the covariation between palatal morphology and craniofacial skeletal patterns in different orthodontic patients and also the relationship between palatal shape and skeletal patterns in adults with Class III malocclusion [19-23]. Quantifying the underlying craniofacial morphology and the analysis of the predictive variables' stability is crucial to planning the best treatment for these patients [24]. Therefore, the present study aimed to investigate the palatal and craniofacial morphology in Class III growing patients by Geometric Morphometric Analysis (GMM) and to identify the differences between a success and a relapse treatment group after early orthopedic Class III treatment.

PATIENTS AND METHODS

This project was approved by the Ethical Committee of the University of the University of Rome Tor Vergata (Protocol number: 201/19).

31 patients (19 m, 12 f, 8.3 y ± 5 m) from Hospital of Rome Tor Vergata, treated with RME/FM/BB protocol were retrospectively enrolled. Caucasian ancestry, Class III skeletal malocclusion early mixed dentition, CS1-CS2 skeletal maturation [25], absence of pseudo-class III and no congenital diseases were the inclusion criteria. The treatment protocol was represented by a rapid maxillary expander (RME) bonded on the first permanent molars. RME had also hooks on the buccal surface provided for the facial mask (FM). When the transversal overcorrection was achieved through the activation of RME, FM with extra-oral elastics on the hooks were used for maxillary protraction (each patient wore the mask about 15 hours daily). To control the vertical divergence, an acrylic bite-block appliance (BB) with occlusal bite planes was used (20 hours daily) [26].

The whole sample achieved the orthopedic Class III early correction successfully. Follow-up visits were performed every 6 months, until patients reached a CS4 maturation and a complete permanent dentition (average age of 14.5y ± 5m). For each patient, x-rays (cephalograms and panoramic) and dental casts were provided before the orthopedic phase (T0) and before the orthodontic phase (T1). Linear measurements performed on the lateral cephalograms are shown in Figure **1** [27]. Upper and lower dental casts were scanned through the extraoral scanner OrthoXscan, exported in a STL file and analyzed through Viewbox [28]. (Figure **2**):

Maxillary anterior width (Max-AW): transversal distance between the cusp of canines.

Maxillary posterior width (Max-PW): transversal distance between upper right and left first permanent molars.

Maxillary anterior length (Max-AL): sagittal distance from the palatal midpoint between upper incisors to a line drawn by the center of left and right first premolars.

Maxillary posterior length (Max-PL): sagittal distance from the palatal midpoint between upper incisors, to the Max-PW.

Maxillary-molar alveolar width (Max-W): distance between right and left first molar, at the conjunction between the gingival border and lingual sulcus.

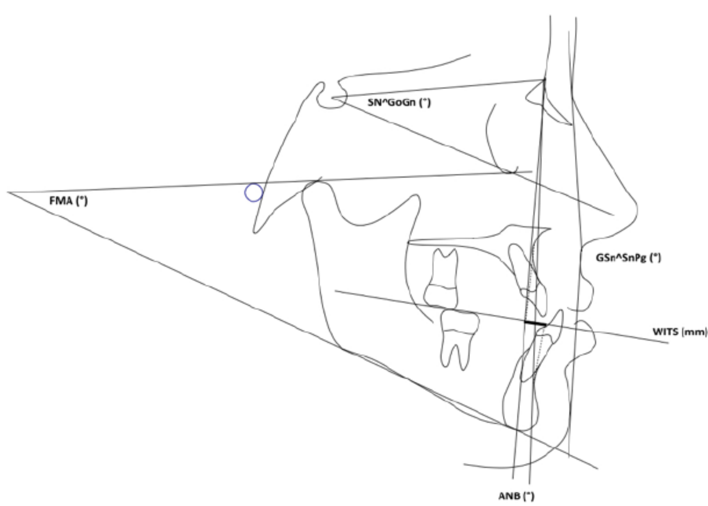

Figure 1: Cephalometric measurements performed at T0 and T1 on lateral radiographs.

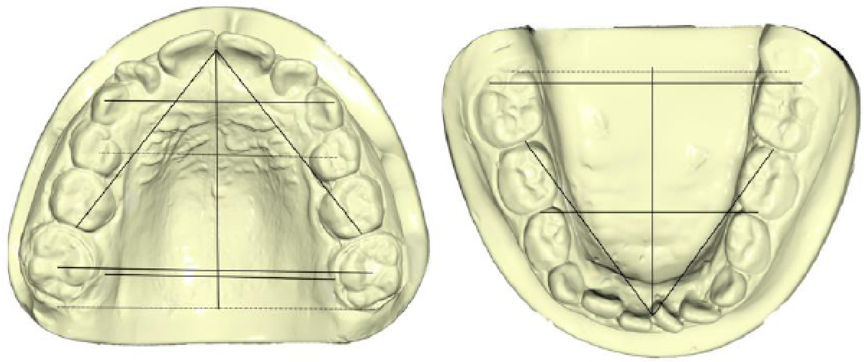

Figure 2: Measurements performed at T0 and T1 phase on digital dental casts.

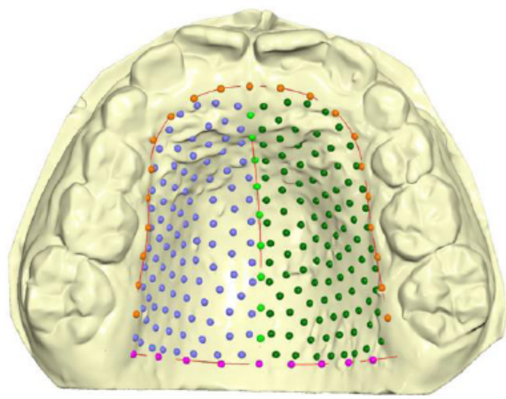

Figure 3: Palatal Area with three curves drawn on the digital casts.

Mandibular anterior width (Md-AW): transversal width between the tips of primary first lower molars or between interproximal premolar points.

Mandibular posterior width (Md-PW): transversal width between the buccal distal cusp of lower first molars.

Mandibular anterior length (Md-AL): a sagittal distance from the lingual incisor midpoint to the Md-PW.

Mandibular posterior length (Md-PL): a sagittal distance from the lingual incisor midpoint to the Md-PW.

Two groups were identified: a bad responder group (BR) and a good responder group (GR). BR group was composed of 19 patients, 12 males and 7 females (12.1 years ± 3 months), and still presented a Class III malocclusion and the necessity of a second phase of treatment. GR group was composed of 12 patients, 7 males and 5 females (12.7 years ± 2 months) showing a Class I occlusion and favorable aesthetic of soft tissues.

Three-dimensional geometric morphometric (3D GMM) was performed on digital casts and lateral cephalograms by Viewbox in the pre-treatment phase (T0). The analysis was performed after the digitation of three curves and 239 landmarks (Figure **3**) resulting in three variables:

- the sagittal palatal suture (nine landmarks),
- the upper arch perimeter, through the gingival sulcus of upper teeth (twenty-one landmarks),
- the posterior curve, through the distal sulcus of the upper first molars, orthogonal to the sagittal palatal suture (nine landmarks).

The craniofacial shape was analyzed on lateral cephalograms by 16 continuous curves and 120 points. Palatal and craniofacial mean values were set as reference points to allow all semilandmarks to be more adaptable for each patient. All digitizations were done by one trained examiner (FCDR) and analyzed by Procrustes analysis. Measurements on digital dental casts were repeated by the examiner 15 days later, using a paired t-test (systematic error, p-value < 0.05).

In a pilot study, ten patients were used to calculate the reproducibility and the sample size which indicated the need for approximately twenty-two patients to estimate the maxillary anterior width with a 95% confidence interval (CI) with a minimum difference of 2.5 mm and a standard deviation (SD) of 2.5 mm (power of 80%). Descriptive statistics were assessed with a t-test (level of significance = 5%). Bad response or good response results were added to each patient's pre-treatment data and each measurement was analyzed using a stepwise discriminant analysis [29, 30]. Procrustes analysis was performed using Viewbox 4, and a principal component analysis (PCA) was also applied to investigate the principal variations of maxillary and craniofacial skeletal morphology by MorphoJ software. A PLS, *i.e*. the two-block partial least squares analysis, was used to evaluate the covariation between palatal and craniofacial shapes. The RV coefficient of Escoufier was used as a scalar measure of the strength of covariation between the two sets of landmarks [31].

RESULTS

A non-significant mean random error was found (6.35% for upper digital casts and 8.65%). Table **1** shows the cephalometric descriptive statistics. The sample was made of thirty-one subjects with Class III (ANB = −0.9°; Wits = −6.3 mm) and a normal divergence (FMA = 27°; SN^GoGn = 35°).

Table 1: Cephalometric Description of the Collected Sample before Treatment (T0)

31 subjects (19 males, 12 females, 8.3 years ± 5 months)		
	M	SD
FMA°	27	3,5
ANB°	-0,9	1,4
Wits(mm)	-6,3	4,2
Sn^GoGn°	35	4,4

Regarding vertical and sagittal cephalometric measurements, no significant statistical differences were found between BR group and GR group at T0. At T1, the cephalometric analysis showed an increased divergence (FMA = 30.8°±3.8°; SN^GoGn = 38.9°±2.3°), a reduction of ANB (1.3° ± 1°) and of Wits appraisal (−11 mm ± 3.7 mm) in R when compared to S. Results are shown in Table **2** and Table **3**.

At T1 differences between BR and GR were found in digital casts analysis (Table **5**). The maxillary anterior width was larger in BR (32 mm ± 2.8 mm) when compared to GR (29.2 mm ± 3.9 mm). The maxillary anterior length was shorter in BR (14.2 mm ± 3.2 mm) than in GR (18.2 mm ± 3.5 mm) (Table **5**).

Table 2: Cephalometric Analysis: Statistical Comparisons between R and S at T0

	BR		GR			
	M	**SD**	**M**	**SD**	**Diff**	**P**
FMA°	26,9	2,8	25,2	3,7	-1,7	NS
ANB°	-0,7	1,3	-1,5	2	-0,6	NS
WITS(mm)	-8,6	4,1	-6,6	4,1	2	NS
SN^GoGn°	35,7	3,8	33,8	4,4	-1,9	NS

Table 3: Cephalometric Analysis: Statistical Comparisons between Groups at T1

	BR		GR				
	M	**SD**	**M**	**SD**	**Diff**	**P**	
FMA°	30,8	3,8	25,5	4,3	-6,4	**	**
ANB°	1,3	1	2,8	2,3	1,4	NS	
WITS(mm)	-11	3,7	-3,1	2,6	7,9	**	**
SN^GoGn°	38,9	2,3	33,9	3,5	-5,3	**	**

Table 4: Digital Casts Analysis: Statistical Comparisons between Groups at T0

	BR		GR		Diff.	*t* tests
	M	SD	M	SD		*P*
Max-AW	32	2,8	29,2	3,9	-2,8	*
Max-PW	44,2	3,9	43,7	4,45	-0,5	NS
Max-AL	14	1	14,1	2,7	0,1	NS
Max-PL	34,6	4,5	36,8	3,7	2,1	NS
Max-W	33,2	3,4	33	3	0,2	NS
Md-AW	27,1	3,6	26,4	2,5	-0,8	NS
Md-PW	48,1	3,2	47,6	1,9	-0,5	NS
Max-PL	33,1	8	36,9	3,1	3,8	NS
Md-A	62,2	8,1	60,4	6,9	-1,7	NS

Table 5: Digital Casts Analysis: Statistical Comparisons between Groups at T1

	BR		GR		Diff.	*t* test	
	Mean	SD	Mean	SD		*P*	
Max-AW	35,6	3,56	34,52	2,47	-0,7714	NS	
Max-PW	48,35	2,63	46,59	1,75	-1,756	NS	
Max-AL	14,24	3,22	18,24	3,47	4	**	**
Max-PL	37,95	4,87	39,04	2,77	1,094	NS	
Max-W	36,27	3,06	34,68	2,21	-1,593	NS	
Md-AW	29,25	4,57	27,76	3,11	-1,489	NS	
Md-PW	50,41	3,73	49,1	3,17	-1,311	NS	
Max-PL	33,54	8,08	35,04	2,65	2,305	NS	

The palatal shape evaluation at T0 is graphically descripted in Figure **4**. The analysis of the first three components (PCs) was found statistically significant. In particular, the first principal component (palatal-PC1) had a great variance (44%) and showed variations in all three special planes, principally distributed along vertical and transversal planes.

Palates with the highest vault were correlated to a narrow shape, while wide palatal shape had a shallow vault. The second principal component (palatal PC2, 18%) showed significant differences only in palatal height. (Figure **4**)

Regarding the craniofacial morphology, four principal components PCs were found statistically significant and represented the 61% of the total shape variability.

As shown in Figure **5**, Craniofacial PC1 (26%) showed differences on the vertical plane, in particular along the ramal height of the mandible and in the mandibular condyle and symphysis.

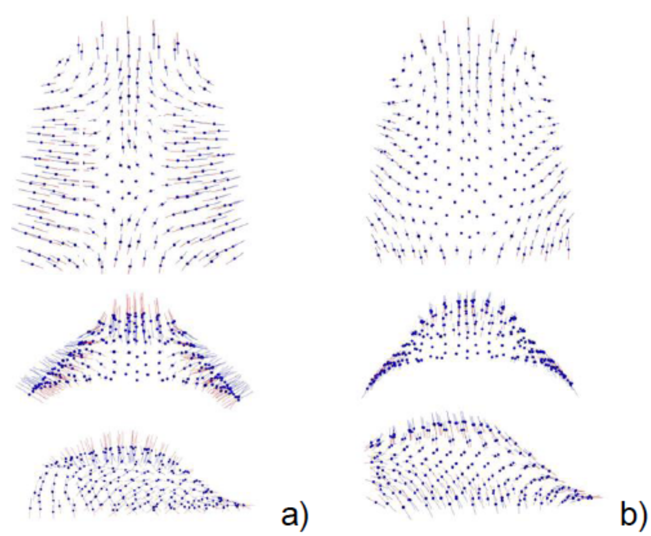

Figure 4: a) Graphic representation of palatal PC1; **b)** Graphic representation of palatal PC2.

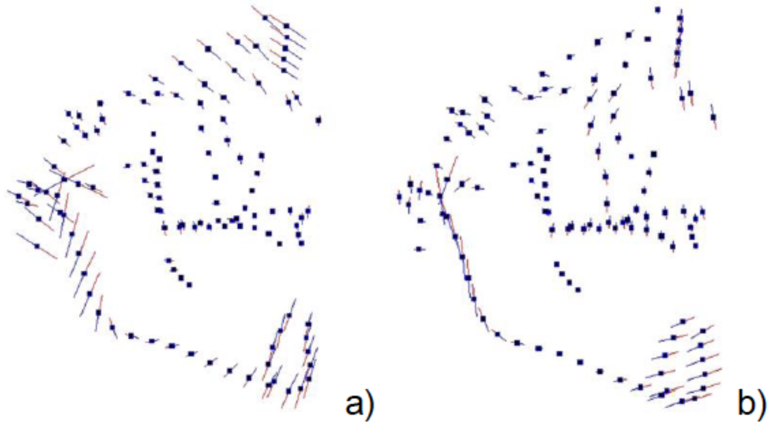

Figure 5: a) Graphic representation craniofacial PC1 of the craniofacial complex; **b)** Graphic representation craniofacial PC2 of the craniofacial complex.

Craniofacial PC2 (16%) showed differences in the sagittal plane, especially in the cranial base related to mandibular shape (Figure **5a**). Partial least square (PLS) analysis found a covariance between palatal and craniofacial skeletal components.

In the examined sample, there was a significant covariation between palatal and craniofacial shape, with a RV coefficient of 0.18. In particular, the first PLS1 represented the 62% of the whole covariation: a higher divergency angle was correlated to a higher palatal vault and a narrower upper arch width. The craniofacial variations were significantly remarkable in the mandibular ramus and in the mandibular condyle and symphysis. The other analyzed variables were not statistically significant.

In Table **6** the differences between T1 and T0 related to BR and GR group are found. Both groups showed significant improvements in both anterior and posterior maxillary arch width because of the orthopedic upper expansion with RME. In BR, both mandibular anterior width ($p < 0,001$) and lower intermolar width ($p < 0,001$) increased at T1. On the contrary, GR presented a statistically significant increase in the maxillary anterior length ($p < 0,001$) and in the maxillary posterior length ($p <0,5$). In BR group the mandibular arch showed no statistically significant changes.

Table **7** shows the results by the discriminant analysis, which produced a two predictive variables-model:

– Maxillary posterior length (0.03)

– Maxillary anterior length (0.01)

Both the variables maximized the Mahalanobis distance between BR and GR group (Wilks' lambda =

Table 6: T1-T0 Changes in the BR and in the GR

Relapse T1-T0			Success T1-T0	
	T1-T0	P	T1-T0	P
Max-AW	3,6	***	5,3	***
Max-PW	4,2	***	2,9	*
Max-AL	0,3	NS	4,2	**
Max-PL	3,3	NS	2,3	*
Max-W	3,1	***	1,7	NS
Md-AW	2,1	***	1,4	NS
Md-PW	2,4	***	1,5	NS
Md-AL	0,9	NS	0,6	NS
Max-PL	0,5	NS	-1,8	NS

Table 7: Discriminant Analysis of Predictive Success Variables in Class III Early Orthopedic Treatment

Groups	N°	BR		GR		Costants (Fisher's linear discriminant function)	Predictive Variables	Standandardized canonical discriminant function coefficients
		N°	%	N°	%			
RELAPSE	19	15	79	4	21	-33,4	*Maxillary posterior lenght*	1.1
SUCCESS	12	2	167	10	83	-29,9	*Maxillary anterior lenght*	-1.3

Percentage of cases correctly classified: 81%
Discriminant scores for group means (group centroids):
Relapse group = 0,6
Success group = -0,9
Critical score = 0,6

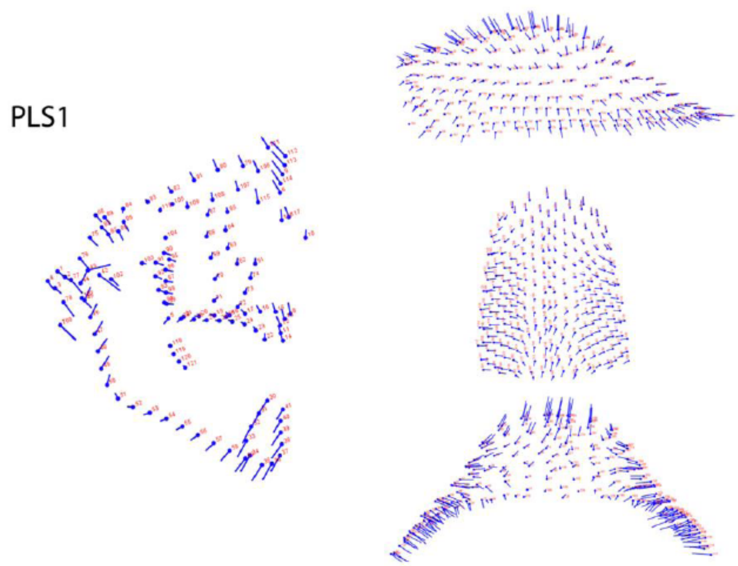

Figure 6: Graphic representation of PLS1.

0,6 with a significance of 0,004). These results allowed the redistribution of five cases into the more appropriate group. The classification accuracy was 81%.

DISCUSSION

A Class III malocclusion successful resolution depends by a plenty of variables: facial morphology and growing pattern, environmental factors, a proper diagnosis followed by an appropriate timing and treatment duration, and children collaboration. The success of early orthodontic treatment with removable appliances such as Bite Block and Facial Mask is highly dependent on patient compliance, defined as the extent to which the patient's behavior matches the practitioner's recommendations [32, 33]. The variations in transverse, vertical, and anteroposterior skeletal morphology are linked to palatal development [34-37]. This retrospective study focused on the analysis of growing subjects with Class III malocclusion using three-dimensional measurements to investigate the correlation between Class III malocclusion skeletal components. To our knowledge, only few studies analyzed the correlation between palatal morphology and facial skeletal components [18-24]. Despite the different analyzed samples, previous studies revealed comparable results to the ones found in our analysis. The results of this study highlighted a strong correlation between the palatal transversal and craniofacial vertical measurements. This suggests that clinicians should carefully analyze the discrepancies in the diagnostic process of Class III malocclusion focusing on a 360° analysis of the patient, [38]. Since both maxillary anterior and posterior transversal dimensions were found to be significantly reduced in this malocclusion, Class III malocclusion growing patients require orthopedic maxillary expansion [39-41]. The discriminant analysis of the treatment stability selected the maxillary posterior width and maxillary anterior lengths as two significant predictive variables. Before treatment, relapse patients have a shorter and wider morphology of the maxilla. At the end of the treatment, BR group showed no significant improvement in the maxillary length when compared to GR. Moreover, relapse in BR is more complicated by the mandibular width increase. These results agree with the literature in which an unfavorable prognosis of Class III malocclusion is frequent when the patient shows a narrow upper arch, open gonial angle, and an increased divergence [37-41]. The cephalometric analysis revealed that at T0 no statistically significant differences were evident. On the contrary, at T1 BR showed an increased vertical divergence, while GR showed a normal divergence. These results agree with other studies [8-16], in which it is reported that the vertical growth pattern represents an unpredictive variable in Class III malocclusion. Thus, the vertical control in Class III malocclusion growing patients may be advisable Our results advise clinicians to plan a second phase of Class III treatment carefully and correctly because a proper diagnosis and treatment objectives are necessary for the clinicians and for the patients [42, 43].

Class III malocclusion correction usually involves maxillary expansion, proclination of the upper incisors contemporary to the retroclination of the lower incisors with interproximal enamel reduction to improve the dental occlusion and the facial profile. [45-47] The range of skeletal and dental changes in response to orthodontic treatment suggests that Class III treatment can be successfully obtained with dental movement without negative effects to the periodontium [48]. The limitations of this investigation are the retrospective nature of the study and the reduced sample size. This is because of the low prevalence of Class III malocclusion in Caucasian ancestry (around 4.3% as reported by Perillo *et al*. [48]) and the difficulty in following up with patients after the first phase of treatment. The prevalence of Class III malocclusions varies greatly among and within different races, ethnic groups, and geographic studied regions. The discrepancies in the prevalence rate might be another limitation of our study. Another limitation is the absence of an untreated control group for the ethical necessity to treat these patients as soon as possible to achieve the orthopedic correction of Class III malocclusion [3, 4].

CONCLUSIONS

· In Class III malocclusion, increases in vertical divergence are correlated with a higher palatal vault and narrower width.

· A wider and shorter maxillary morphology could be a relapse factor for Class III orthopedic treatment, while the lack of mandibular changes could be predisposing for treatment success.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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