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Rapid Maxillary Expansion Based on the Correlation of the Maturation Between the Midpalatal and Zygomaticomaxillary Sutures through CBCT

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Abstract

Aim: The aim of this study was to evaluate and correlate the degree of maturation of the midpalatal suture (MPS) and zygomaticomaxillary suture (ZMS).
Methods: The sample consisted of 160 orthodontic patients, aged between 11 and 20 years, 59 men and 101 women, from archives of private clinics. Patients who presented Cone Beam Computed Tomography (CBCT) images in their initial orthodontic file were selected. CBCT images were exported to the InvivoDental5 program (Anatomage, San Jose, California), where axial MPS sections were used to evaluate the maturation stage, and cross-sectional sections in the coronal plane were used to evaluate the maturation of the ZMS. Spearman's correlation coefficient, McNemar-Bowker symmetry test and kappa agreement test with quadratic weighting were used to assess the correlation between the maturation stages of MPS and ZMS. Ordinal logistic regression analysis was used to verify the effect of age and gender on the classification. In all statistical tests, a significance level of 5% was adopted.
Results: The MPS and ZMS displayed a significant correlation between their maturation stages. ZMS tended to present earlier maturation. Taking into account only the individuals from MPS stage C, an earlier ZMS stage was observed in 4.4% while a more advanced ZMS stage was observed in 24.37%. Among older individuals, this prevalence was 36.36%, thus 69.69% had an unfavorable prognosis for RME, following the proposed method.
Conclusion: The correlation between the maturation stages of MPS and ZMS increases the reliability of the RME prognosis through individual morphological evaluation of sutures.

Keywords: Cone beam computer tomography, Cranial sutures, Expansion, Maturation

1. Background

The concept that the maxilla can be expanded by opening the palatal suture was first introduced by Angell (1) 150 years ago. However, it was not until 1961 that rapid maxillary expansion (RME) procedure became routine in orthodontic practice (2). Although several studies have correlated the possibility of RME with skeletal age of patients (3-5), there is still lack of information on how far conventional RME is worth performing or using resources such as mini-implant support or even surgical assistance (6-13) to enhance the expected result. A reliable diagnostic method for this purpose is important since both the use of temporary anchorage devices and surgical care make the therapy more invasive, with an uncomfortable postoperative period and greater morbidity, in addition to raising the cost of treatment and presenting greater risk for the patient (3,6,7).

Based on that, Angelieri et al.(10) described an evaluation method that provides parameters to assess the degree of maturation of the palatal suture according to morphological findings described in previous studies (13-16) and, thus, guide the professional in choosing the therapy to be used in order to obtain the best orthopedic response. Five maturational stages of the midpalatal suture (MPS) were described according to its morphology (10). In the early stages of maturation, classified as A and B, RME would have a good prognosis (9) unlike the more advanced stages (D and E), where the probability of suture opening is limited due to its high degree of fusion (8,17-19). The limitation of this evaluation method is based on intermediate stage C, whose prognosis of RME still raises doubts, since it has been the most prevalent stage both among younger and older individuals (7-10,17,20-22).

In 2017, a similar methodology was used to determine the morphology of the five maturational stages of the zygmaticmaxillary suture (ZMS),thus, determining its clinical impact. The authors (23,24) observed that in the early stages (A and B), the orthopedic response of the ZMS to maxillary protraction (MP) forces were optimal, while in stage C the skeletal gain was limited.

Currently, it is known that the ZMS plays a role in RME, exerting resistance forces to orthopedic mechanics (3,16,23,24). Thus, aiming at potentiating the prognosis of RME, the hypothesis was to evaluate the maturation stages of the midpalatal and ZMSs, trying to correlate them in a sample of individuals between 11 and 20 years of age. Thus, it will be possible to establish not only the possibility of hemimaxilla protraction, but also to determine the expected quality for orthopedic action, guiding the choice either for conventional expanders or by the rapid expansion of the maxilla with the aid of micro-implants (miniscrew-assisted rapid palatal expansion -MARPE).

2. Methods

The research project of this study was submitted to the Research Ethics Committee of the Sacred Heart University Center (UNISAGRADO) and was approved under number 3.574.735.

Sample calculation

The sample size calculation was based on the hypothesis that there was a statistically significant correlation between the two classification methods, evaluated by Spearman's correlation coefficient. This hypothesis is based on a previous study (25) that found such a correlation. For the calculation, a significance of 5% and a test power of 80% was adopted, and adjustment for non-parametric procedure was based on Asymptotic Relative Efficiency (ARE: n = n′/ 0.91). To demonstrate a minimum correlation of 0.25, at least 137 subjects would be required. As archive data were used and in order to better represent all stages of maturation, the sample was increased to include all individuals who met the inclusion criteria, totaling 160 individuals.

Sample selection

This retrospective study comprised a sample of 160 patients, 101 females and 59 males, aged between 11 and 20 years (mean age 15 years and 5 months), from the archive of orthodontic patients from private practices. All patients signed a documentation provision term.

The individuals were then divided into two groups according to age range. The first group comprises those aged between 11 and 15 years, in whom a favorable prognosis for RME was expected (9), and the second group with subjects aged 16 to 20, in which the prognosis became dubious (8).

Inclusion criteria

These patients had been previously selected according to the following inclusion criteria: non-syndromic patients with no growth hormone disorder, no developmental problems, and no history of previous orthodontic treatment and with CBCT images as part of their orthodontic file.

Methodology

CT scans were obtained from private clinics using an iCat scanner (Imaging Sciences–Kavo®) with standardization of the head position and with the following specifications: 22x16cm FOV (Field of View), 0.4 mm voxel, 40 seconds of exposure, 120 KVp and 36 mA. To obtain standardized CBCT images, patients were instructed to maintain the natural position of the head and occlude in maximum habitual intercuspation (MHI).

The InvivoDental5 (Anatomage, San Jose, California) software was used to view and evaluate the tomographic images. The procedure used to obtain images to evaluate the MPS was performed according to the methodology described in previous articles (8,9,10,17). Similarly, the methodology used to obtain images of the ZMS was based on previous studies (23,24).

Initially, the image was positioned without tilting, using the reference lines as a guide. Thereafter, in the sagittal section, the horizontal reference line was positioned passing through the tip of the nose, thus visualizing the ZMS bilaterally in the axial section. The horizontal reference line was then positioned through the two sutures, allowing its visualization in the coronal section. Finally, the vertical line was positioned over the right ZMS in the coronal section for evaluation. Counterclockwise rotation was performed for better positioning. The evaluation was then performed on the image that appeared in the sagittal section, considering the entire suture.

A total of 320 images were thus obtained, half of the MPS and the other half of the ZMS for each of the 160 individuals. The images were evaluated blind by two previously calibrated evaluators, who interpreted the cross-sectional tomographic sections in the axial plane to determine the maturation stage of the palatine suture and the cross-sectional cut in the coronal plane to evaluate the maturation of the ZMS.

For each patient, the evaluators identified the maturational stage of the MPS, stages A, B, C, D or E, as described below:

In stage A, the MPS is almost a high density straight line with no or very little interdigitation (Fig. 1A). Similarly, the ZMS is uniform, but following a tortuous path, as a high density line with reduction of bone density around it (Fig. 1a).

In stage B, both the MPS (Fig. 1B) and the ZMS (Fig. 1b) assume an irregular shape, with a more sinuous high density line, when compared to the previous stage.

In stage C, the MPS appears as two lines of high density, parallel, scalloped, and separated by small areas of low density (Fig. 1C and 1c).

In stage D, the fusion of the MPS has already occurred in the palatine bone, with progressive maturation from the posterior to the anterior region (Fig. 1D). In the ZMS (Fig. 1d), fusion has already occurred in its lower part, therefore in this region the high density line cannot be visualized.

In stage E, the suture is no longer visible, indicating its complete fusion (Fig. 1E and 1e).

Measurement error assessment

To verify the reliability of the suture classification method, the evaluation of the 320 images was repeated by a second examiner (inter-examiner error), and were also repeated by the first evaluator eight days after the first evaluation to verify the intra-examiner error. The same images were used in both evaluations since it is expected that orthodontists do not need to obtain the slices, but only interpret it. For those images with disagreements, stage determination was assigned to the first evaluator because of his high experience.

Statistical Analysis

The data were presented by absolute (n) and relative (%) frequencies.

The inter and intra-examiner errors were evaluated by the kappa statistic and the result was interpreted according to Landis and Koch (26). The following tests were used to analyze the classification of maturation stages between the sutures: Spearman's correlation coefficient to verify the degree of correlation; the McNemar-Bowker symmetry test to determine whether any method tended to classify with higher values than the other; and kappa with quadratic weighting to determine the agreement between the methods.

Spearman's correlation coefficient was used to verify the correlation between the maturation stages and age, and ordinal logistic regression analysis was used to verify the effect of age and gender on the classification, with classification as the dependent variable and age and gender as independent variables.

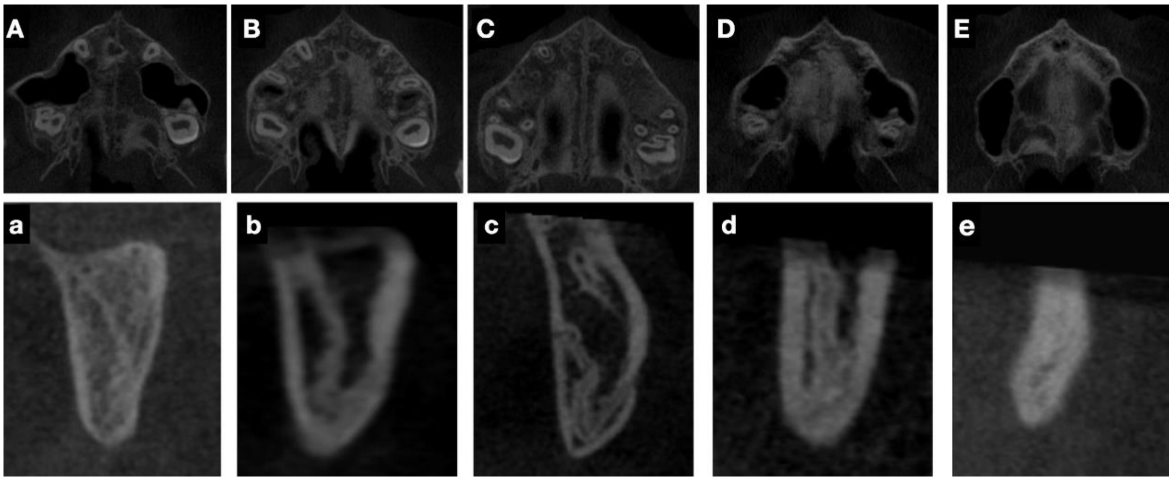

Figure 1. Representative sections of each of the five maturational stages of the midpalatal (A-E) and zygomaticomaxillary suture (a-e). Aa, stage A showing the suture as a radiopaque line; Bb, in stage B the suture

becomes a little more sinuous; Cc, in stage C, the suture presents as two parallel radiopaque lines; Dd, in stage D the suture cannot be visualized in part of the bone; Ee, in stage Ee, the suture is no longer seen in almost its entirety.

A significance of 5% (p<0.05) was adopted in all tests. All statistical procedures were performed in the SPSS software, version 26.

3. Results

The kappa value for the intra-examiner error was 0.86 and 0.84 for the inter-examiner error, being 0.83 for the inter-examiner error for the ZMS, and 0.80 for the intra-examiner error. In both, the agreement was considered "almost perfect" according to Landis and Koch.26

The most frequent stage of maturation of the MPS in the population studied (Table 1) was stage C (61.25 %%), followed by stages B (16.25%), D (15.62%) and E (6.25%). Stage A was only observed in one individual (0.62%). There was also a higher prevalence of stage C, both in individuals aged between 11 and 15 years old (28.75%) and in individuals aged between 16 and 20 years old (32.50%). However, for younger individuals, stage B appears as the second most frequent (7.50%) while for older individuals, stage D (14.38%) is the second most frequent. When we evaluated the extreme stages, we observed that no individual was evaluated as stage E in the youngest sample, and no individual was evaluated as stage A in the older sample.

Table 1 also presents the distribution by age of the maturation of the ZMS. There is a higher prevalence of stage C (55.63%), followed by stages D (30.00%), E (8.75%) and B (5.62%). Stage A was not observed. When considering age groups, stage C was the most prevalent among younger individuals (31.88%). However, for those aged 16 to 20 years, stage D was the most prevalent (28.12%).

Table 2 shows the correlation of the independent variables age and gender with the evaluation methods. For both methods, regression analysis showed a statistically significant influence on age regarding classification, but not on gender.

The maturation stage of MPS to that of the ZMS is described in Table 3. The agreement between the two methods using the weighted kappa was statistically significant (k=0.25; p=0.001*). Of the total sample, disagreement was observed in one stage on the scale in 85 cases (53.1%), and in 14 cases (8.8%) it was in two stages. The correlation between the two methods was statistically significant, but very weak (r=0.27; p<0.001*). In 38.2% of the cases, the two methods agreed with the same classification. However, in 43.8% of the cases, the ZMS assessment provided a more advanced classification than the SPM, and in 18.12 of the ZMS cases it provided a less advanced classification than the SPM. This shows that there is a general tendency for ZMS to classify later stages than SPM, which can be confirmed by the McNemar-Bowker symmetry test (p=0.021*).

Table 4 presents the prevalence of different maturation stages of the ZMS for individuals classified as stage C of the MPS, within the total sample. Stage B was observed in 4.38% of the individuals who have MPS in stage C, 32.5% presented both sutures in stage C, the zygomatic-maxillary suture is in stage D in 20.62% of individuals, and 3.75% are in stage E. For individuals between 11 and 15 years of age, the majority of the total sample (62.30%) had both sutures in stage C maturation. Among the older individuals, 2.02% of those classified as stage C of midpalatal maturation presented the zygomatic-maxillary suture in stage B, 14.14% in stage C, 30.30% in stage D, and 6.06% in stage E.

The individuals were placed into three groups based on conclusions from previous studies (9,10,11,2) (Figure 2):

Favorable prognosis: those classified in stages A and B of palatal maturation, plus those classified in stage C with ZMS in stages A or B.

Doubtful prognosis: individuals with midpalatal and ZMS in stage C of maturation.

Unfavorable prognosis: stages D and E of palatal maturation, plus those in stage C associated with

Table 1. Relationship between the maturation stages of the midpalatal and zygomaticomaxillary sutures by age group.

Suture	Facial Suture Maturational Stage A	B	C	D	E	TOTAL
			N (%)			N (%)
Midpalatal	1 (0.62%)	26 (16.25%)	98 (61.25%)	25 (15.62%)	10 (6.25%)	160 (100%)
11-15 years old	1 (0.62%)	12 (7.50%)	46 (28.75%)	2 (1.25%)	0 (0.0%)	61 (38.12%)
16-20 years old	0 (0.0%)	14 (8.75%)	52 (32.50%)	23 (14.38%)	10 (6.25%)	99 (61.88%)
Zygomaticomaxillary	0 (0.0%)	9 (5.62%)	89 (55.63%)	48 (30.00%)	14 (8.75%)	160 (100%)

11-15 years old	0 (0.0%)	6 (3.75%)	51 (31.88%)	3 (1.88%)	1 (0.62%)	61 (38.12%)
16-20 years old	0 (0.0%)	3 (1.88%)	38 (23.75%)	45 (28.12%)	13 (8.12%)	99 (61.88%)

Table 2. Ordinal logistic regression analysis with classification as a dependent variable and age and gender as independent variables.

Dependent variable	Independent variable	Estimate	SD	p
Midpalatal suture	Age	0.259	0.061	<0.001*
	Gender	0.219	0.329	0.504
Zigomaticomaxillary suture	Age	0.404	0.070	<0.001*
	Gender 0=Fem, 1=Male	-0.073	0.333	0.827

* - statistically significant (p<0,05)

ZMS in stages D and E.

Accordingly, for 11- to 15-year-old individuals, 29.50% had a favorable prognosis, 62.30% had a doubtful prognosis, and only 8.20% had a poor prognosis. For the population over 16 years of age, 16.16% were in the favorable prognosis group, 14.14% had doubtful prognosis, and 69.69% had a poor prognosis.

Table 3. Sample distribution comparing MPS and ZMS classifications.

		Zigomaticomaxillary									
		B		C		D		E		Total	
		n (%)		n (%)		n (%)		n (%)		n (%)	
midpalatal	A	0	(0.0)	1	(0.6)	0	(0.0)	0	(0.0)	1	(0.6)
	B	2	(1.3)	20	(12.5)	3	(1.9)	1	(0.6)	26	(16.3)
	C	7	(4.4)	52	(32.5)	33	(20.6)	6	(3.8)	98	(61.3)
	D	0	(0.0)	13	(8.1)	6	(3.8)	6	(3.8)	25	(15.6)
	E	0	(0.0)	3	(1.9)	6	(3.8)	1	(0.6)	10	(6.3)
	To	9	(5.6)	89	(55.6)	48	(30.0)	14	(8.8)	160	(100.0)

r Spearman = 0,27; p<0,001*

kappa weighted = 0,25; p=0,001*

McNemar-Bowker c2 = 20,95; p=0,021*

Table 4. Relationship between maturation stages of the midpalatal and zygomaticomaxillary sutures by age group.

Age Group	Facial Suture Maturational Stage					
	CA	CB	CC	CD	CE	TOTAL
			N (%)			N (%)
11-15 years old	0 (0.0%)	5 (8.19%)	38 (62.30%)	3 (4.92%)	0 (0.0%)	61 (100%)
16-20 years old	0 (0.0%)	2 (2.02%)	14 (14.14%)	30 (30.30%)	6 (6.06%)	99 (100%)
11-20 years old	0 (0.0%)	7 (4.38)	52 (32.50%)	33 (20.62%)	6 (3.75%)	160 (100%)

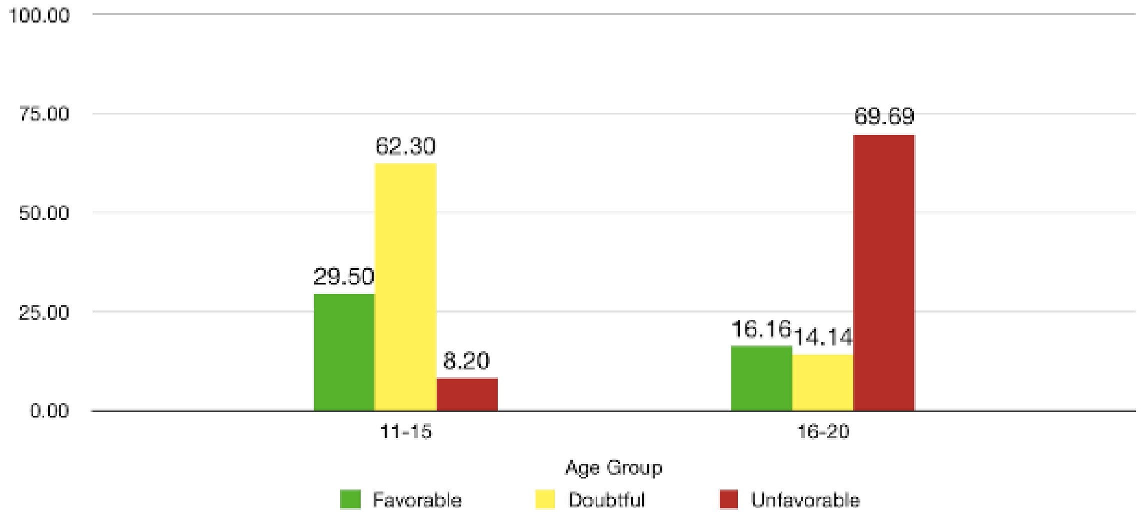

Figure 2. Distribution of individuals according to prognosis

4. Discussion

It is undeniable that RME is a successful clinical protocol with great results in current orthodontic practice and is therefore widely performed by professionals. Precisely because of this widespread popularization, it is unacceptable that there is still no way to determine the prognosis of skeletal expansion.

To bridge this gap, in 2013 an evaluation method of the maturation of the palatine suture by CBCT was suggested in which five stages were determined (10). Results presented in Table 1 of the present study revealed that stages A and B have a higher prevalence (8.12%) than stages D and E (1.25%) between patients 11 and 15 years of age. For those above 16 years, stages D and E (20.63%) were more prevalent than stages A and B (8.75%). This distribution agrees with previous studies (7-9,25). These results led the authors to suggest that stages A and B, present in young individuals with no sign of suture calcification, would present a favorable prognosis for RME. On the other hand, rapid expansion of the maxilla assisted by mini-implants would be better indicated for stages D and E.27

Regarding stage C, our data corroborate previous studies (8,9,25). Table 1 shows a 61.25% prevalence of stage C within the total sample. Furthermore, when isolated by age, this stage is the most prevalent in both age groups. The high prevalence of stage C in different age groups reaffirms the uncertainty of the prognosis for RME in individuals in such stage.

Although, according to published reports, the MPS is mainly responsible for the response to expanding orthopedic forces, the other circummaxillary sutures also participate in this action, exerting resistant forces (3,21,23,24). Perhaps in individuals with the midline suture without any degree of ossification, the participation of adjacent structures is not relevant, but in borderline individuals, the degree of fusion and, consequently, of the resistance exerted by the ZMS may be a decisive factor in the quality of the desired orthopedic gain.

The results of the maturation of the ZMS indicate that the most prevalent stages were, in decreasing order, C, D, and E, 58.75%, 30.00% and 8.75% respectively (Table 1). These were also the most prevalent stages observed by Ok et al.(26) (2020), being found in 83.3% of the sample from patients 11 to 20 years of age.

A higher similarity between stage distributions was observed when we evaluated only individuals over 15 years of age. In the study by Angelieri et al.(23), it was observed that stage E was present in 80% of the population studied, with the absence of stage A or B. Our study shows that in the age group between 16 and 20 years of age, stage B was one of the least prevalent (1.88%). On the other hand, stage D presented a prevalence of 28.12% in the age group between 16 and 20 years of age, being the most common in these individuals. These data demonstrate a tendency of the ZMS to terminate fusion earlier when compared to the MPS.

That same tendency was reported by Ok et al.(25), who verified a more advanced maturation of the ZMS in individuals aged between 7 and 30 years. Clinically, this corroborates several articles that report that it is only possible to obtain an efficient orthopedic response of this suture for MP up to a maximum of 10 years of age, while RME presents good results up to 15 years of age (28,29).

Based on our findings, stage C of the ZMS, unlike the MPS, may have an unfavorable prognosis for orthopedic mechanics of maxillary protraction due to its high prevalence observed in a sample of individuals above 11 years of age when the success of orthopedic treatment is not predictable. This was the conclusion of a clinical study (22) that evaluated the orthopedic response in relation to maxillary protraction at different stages of fusion of the zygomatic maxillary suture. The authors concluded that individuals in stages A and B showed excellent results, while individuals in stage C showed very limited orthopedic gains.

According to Table 2, the gender of the individuals did not influence the classification of sutures based on the results of the regression analysis. This same conclusion was obtained by Jimenez-Valdívia et al.(7) who stated that gender is not a reliable factor in determining whether there is suture fusion, based on tomographic images of 200 individuals (95 men and 105 women). Similarly, Angelieri et al.(30) did not observe any correlation between gender and maturation stage of the palatine suture in a sample of 78 individuals.

However, in contrast to previous studies (7,30), the present study observed a correlation between the maturational stage and chronological age (Table 3). This correlation, albeit weak, was also observed in the study by Jang et al.(3). Other studies (3,8-10,17,20,25,27) had already reported this relationship stating that, as individuals aged, the higher is the prevalence of suture fusion. However, we must emphasize that the objective of this method is to identify the maturation phase of the individual, thus enabling a more adequate diagnosis in order to obtain the best possible orthopedic response, either with conventional expansion or with implant-supported expansion. Thus, the correlation with chronological age must be viewed as a trend, but not as a way to determine a definitive prognosis.

When assessing the correlation between the maturation stages of the sutures (Table 3), a significant correlation between the maturational stage of the palatal and ZMS was observed. This correlation was also observed by Ok et al.(25) when performing a retrospective study with 314 individuals, obtaining correlation values of r=0.816.

Table 3 confirms the discussion above, only 18.2% of the sample presented the ZMS at a less fused stage than the MPS. It is interesting to note that within the total sample, 36.9% present the MPS in stage C and the ZMS at an equal or earlier stage, while 24.4% were classified as C for the MPS with the ZMS being more fused. That is, these values allow us to differentiate individuals in stage C of the MPS, a prevalent stage in all age groups (3,8-10,17,25,27), indicating who would present more or less resistance to orthopedic forces with consequent repercussion on their prognosis and therapeutic decision.

On the other hand, for individuals in stages D and E of midpalatal maturation, there was still a high prevalence of the earlier stages of the ZMS. However, since the palatal suture is already partially fused, the prognosis is no longer favorable and, therefore, this correlation is clinically insignificant.

Therefore, from now on, we shall adopt a reference to the zygomaticomaxillary maturation stage for stage C of palatal maturation. For example, individuals who present palatal suture in stage C and ZMS in stage E will be categorized as stage CE. This nomenclature will not be applied to the other stages due to poor clinical relevance. Thus, we adopted stages A, B, CX, D, and E, where X would be the ZMS stage.

Table 4 shows the prevalence of the CX stage within the total sample. In 2017, Angelieri et al.(22) found that only stages A and B of the ZMS present good orthopedic response, i.e., that the ZMS does not exert resistance. Thus, stage CB (4.38%) would have a more favorable prognosis than CC (32.50%), CD (20.62%), and CE (3.75%). These values alone make the RME limit more precise without the aid of skeletal anchorage.

Table 4 also indicates that the CB stage is more prevalent in younger individuals than in those over 16 years of age (8.19% and 2.02%, respectively). On the other hand, stage CD is more prevalent in older than in younger individuals (30.30% and 4.92%, respectively). Stage CE was not observed in any individual up to 15 years old.

Based on these results, we grouped stages CA and CB together with stages A and B, in the favorable prognostic group (9). The CD and CE stages were grouped with stages D and E in the poor prognosis group (8). Stage CC, despite poor orthopedic response of the ZMS22, was considered of doubtful prognosis. We chose this classification referring to the prognosis for RME, a therapy in which the ZMS plays a secondary role. In the previous article, the response taken into account was based on the maxillary protraction protocol, in which the ZMS plays a key role.

Figure 2 presents the sample distribution according to prognosis. According to this form of classification, a good clinical result can be expected in 29.50% of individuals between 11 and 15 years of age, well below the 76.2% suggested by Tonello et al.(9). It is worth mentioning here that the authors considered stage C as a favorable prognosis due to its high prevalence in an age group in which clinical success is expected.

These values are in agreement with the conclusion of Lee and Mah (18). After carrying out a retrospective study evaluating the quality of MRE in 480 individuals aged between 7 and 15 years old, the authors concluded that the best skeletal result is obtained when the patient is up to 12 years old.

When we observe older individuals, the prevalence of a favorable prognosis also increases, from 8% in the 2018 study (8) to 16% in the current one. However, for those with contraindication of RME, the value of 47.30% of the previous study increases to 69.69% in the current sample. These data corroborate the conclusion of Shin et al.(27) who stated that stage C in young individuals is a predictor of failure for RME.

Thus, the evaluation of both sutures maturation, palatal, and ZMS, allows a more accurate prognosis for RME, since one more variable is added, reducing the doubts about individuals in stage C of maturation of the palatal suture. This accuracy of the method could be even greater with the clinical response of the ZMS in stage C in relation to RME. For this reason, a clinical study is still essential to resolve existing doubts, but now we appreciate that such a study can be performed only with individuals in stage C of palatal maturation.

Conclusion

The midpalatal and ZMSs present a significant correlation between their maturation stages, and the ZMS tends to present earlier maturation compared to the MPS.

The maturation stages of the MPS and the ZMS display a significant correlation with the individuals' chronological age, but not with gender.

Based on the results obtained, it can be stated that individuals in stages A, B, CA, and CB would present a favorable prognosis for RME, while those classified as CD, CE, D, and E would present an unfavorable prognosis.

Although the maturational correlation between the MPS and ZMS improves the reliability of the method, clinical studies are still necessary to determine the prognosis of individuals classified as CC.

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