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Proposal for the Modification of the Method to Evaluate the Midpalatal Suture Maturation Status

Proposta de Modificação do Método para Avaliação do Status da Sutura Palatina Mediana

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Abstract

The objective of present research was to propose a new definition for the midpalatal suture (MPS) maturational stages through reevaluation of intermediate stages B, C and D. The sample was composed by 158 cone-beam computed tomography (CBCT) of individuals between 11 and 20 years of age (±15.4 years, 86 females and 71 males), divided into two groups: 74 individuals aged 11-15 years and 84 individuals aged 16-20 years. The CBCT scans were applied to evaluate midpalatal suture maturation status and comprised stages previously classified as B (29), C (92) and D (37). Each axial image was subdivided into six parts in the anteroposterior direction, and each portion was classified according to MPS maturational evaluation methodology. New definitions of stages were proposed. The reliability of the method was tested by two examiners and the intra- and inter-examiner concordances were defined for each evaluation through weighted kappa coefficients and 95% confidence intervals. The chi-square test was used to compare the groups. In all statistical tests, a significance level of 5% was adopted. Two new maturational stages were defined: sub-stage C- and sub-stage C+, with prevalence of 12% and 8.9%, respectively, in 11 to 20-year-olds. The redefinition and validation of the maturational stages of MPS, considering the sub-stages C- and C+, may allow to elucidate the difference in the prognosis of Rapid Maxillary Expansion among individuals aged 11 to 20 years. This data should be confirmed through a clinical study.

Keywords: Cranial Sutures. Hard Palate. Maxilla. Palatine Expansion Technique.

Resumo

O objetivo da presente pesquisa foi propor uma nova definição para os estágios maturacionais da sutura palatina média (MPS) por meio da reavaliação dos estágios intermediários B, C e D. A amostra foi composta por 158 tomografias computadorizadas de feixe cônico (TCFC) de indivíduos entre 11 e 20 anos de idade (±15,4 anos, 86 do sexo feminino e 71 do sexo masculino), divididos em dois grupos: 74 indivíduos de 11 a 15 anos e 84 indivíduos de 16 a 20 anos. Os exames de TCFC foram aplicados para avaliar o estado de maturação da sutura palatina média e compreenderam os estágios previamente classificados como B (29), C (92) e D (37). Cada imagem axial foi subdividida em seis partes no sentido anteroposterior, e cada porção foi classificada de acordo com a metodologia de avaliação maturacional MPS. Novas definições de estágios foram propostas. A confiabilidade do método foi testada por dois examinadores e as concordâncias intra e interexaminadores foram definidas para cada avaliação por meio de coeficientes kappa ponderados e intervalos de confiança de 95%. O teste do qui-quadrado foi utilizado para comparar os grupos. Em todos os testes estatísticos adotou-se o nível de significância de 5%. Dois novos estágios maturacionais foram definidos: subestágio C- e subestágio C+, com prevalência de 12% e 8,9%, respectivamente, em jovens de 11 a 20 anos. A redefinição e validação dos estágios maturacionais da MPS, considerando os subestágios C- e C+, podem permitir elucidar a diferença no prognóstico da Expansão Rápida da Maxila entre indivíduos de 11 a 20 anos. Esses dados devem ser confirmados por meio de um estudo clínico.

Palavras-chave: *Suturas Cranianas. Palato Duro. Maxila. Técnica de Expansão Palatina.*

1 Introduction

Transverse maxillary growth deficiency is caused by genetic and environmental factors, or by an interaction between these two factors. Is usually associated with a uni- or bilateral posterior crossbite that can be found in deciduous, mixed or permanent dentition. The correction of transverse maxillary atresia has long been a topic of discussion in the literature. Studies by Haas[1-3] ensured that rapid maxillary expansion (RME) received the scientific and clinical importance it deserved.

The main objective of RME is to adjust the transverse relationship of the upper dental arch by means of orthopedic separation of the hemi-maxilla, providing real gain of bone mass. As a result, there would be adjustment of the upper arch morphology with a consequent increase in perimeter, allowing for an adequate relationship with the lower arch and facilitating future orthodontic correction.[1-7]

In addition to elucidating the effects of RME and demonstrating its efficacy, the understanding of the maturation and fusion processes of the midpalatal suture (MPS) are a topic of interest in the orthodontic literature,[8-14] because orthopedic effects are substantial at early ages [4-7,15] and decreases significantly in adult patients.[4-6,15-17] The therapeutic alternatives for adult patients include a surgical procedure designed to weaken the sutural strength allowing for adequate orthopedic results. However, there are comorbidities

associated with these procedures. The predictability of RME in adolescents and young adults is important because it allows for precise therapy indication, avoiding undesirable side-effects and inappropriate surgical indications.

Therefore, recent studies in cone-beam computed tomography (CBCT)[18-21] have sought to identify the maturational stages of MPS that would allow for more definitive prognosis of RME. Although promising, these method remain inconsistent, because stage C has a prevalence of 50% from 11 to 20 years of age, the same proportion found in the 11-15 and 16-20-year-age groups.[19,21] These data reflects a clear discrepancy between the distribution of stages among the age groups and the clinical evidence base, because it is known that RME is more effective at early ages.

Because stage C can be long, as the maturation process of MPS occurs gradually,[9] this stage can be subdivided according to maturation along the suture in the anteroposterior direction. Therefore, it appears reasonable to propose a more consistent reassessment and redefinition of MPS maturational stages which could increase the prognosis accuracy. So, our main objective is to propose a modified method to evaluate the MPS maturation stages through reevaluation of intermediate stages B, C and D.

2 Material and Methods

The research ethics committee from Unisagrado approved this study under CAAE no. 83542018000005502. All patients signed the document donation form.

CBCT images were obtained from samples from the Department of Orthodontics, Unisagrado, that had already been published in previous studies.[19,21] This was a retrospective study, and the primary justification for performing the tomographic examination of these patients was the diagnosis of retained teeth.

All tomographs were obtained using the i-CAT (Imaging Sciences - Kavo®, Hatfield, PA, USA) CT scanner with standardization of the head position and the following specifications: 22x16cm FOV (Field of View), 40 seconds of exposure, 120KVp and 36mA. This unit features a high-resolution sensor, which allows for images with a 0.4mm voxel (volumetric Picture element). In order to obtain the CBCT in a standardized way, the patients were instructed to maintain the natural position of the head and occlude in the maximum habitual intercuspation (MHI).

2.1 Sample selection

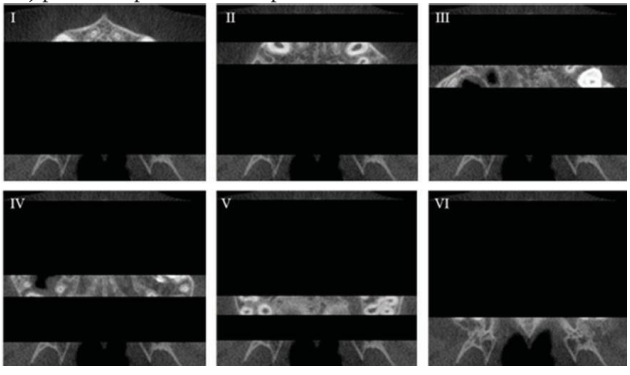
For the evaluation of MPS maturational stages, 158 CBCTs from individuals between 11 and 20 years of age (86 females and 71 males) were analyzed, including previously classified stages[19,21]: B (29 individuals; 14 females and 15 males), C (92 individuals; 52 females and 40 males) and D (37 individuals; 21 females and 16 males). These images were manipulated using the software InVivoDental5 (Anatomage, San Jose, CA, USA) and were evaluated using the axial slice, according to methodology proposed by Angelieri et al.[18]. Two axial slices were considered for subjects with curved palate.

In order to be included, patients should have CBCT images for the diagnosis of retained teeth and have no history of previous Rapid Palatal Expansion. The exclusion criteria were as follow: cleft lip and palate and syndromic patients.

2.2 Evaluation of maturational stages

It was decided to evaluate stage C due to its high prevalence in the 11-15 and 16-20-year-age groups (11-15y; 16-20y).[19,21] Stages B and D were also investigated because of their proximity to stage C. Each image was subdivided in six parts in the anteroposterior direction (Figure 1) as follows: I) premaxilla; II) anterior portion of the maxillary bone; III) middle portion of the maxillary bone; IV) posterior portion of the maxillary bone; V) anterior portion of the palatine bone; and VI) posterior portion of the palatine bone.

Figure 1 - MPS subdivision for the evaluation of maturational stages. I) premaxilla;II) anterior portion of the maxillary bone; III) middle portion of the maxillary bone; IV) posterior portion of the maxillary bone; V) anterior portion of the palatine bone; and VI) posterior portion of the palatine bone



Source: the authors

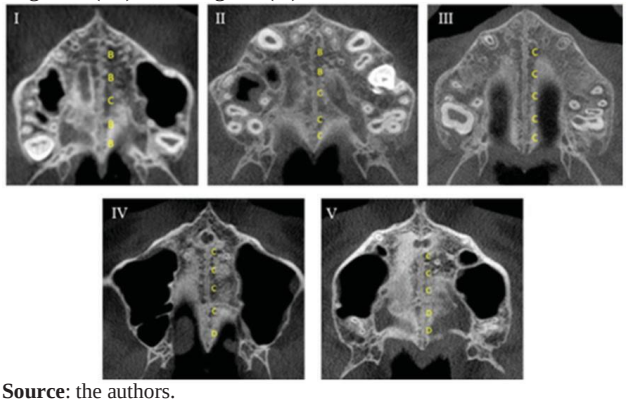
Two orthodontists (V.D.P and L.C.F) reassessed the MPS in the same 158 axial slices previously classified as stages B, C and D. [19,21] The six portions of each MPS were classified and recorded according to the methodology proposed by Angelieri et al.[18]. The evaluation was blind, meaning that during the definition of the maturational stages of each portion of the MPS, the investigators had no information regarding patient data or previously classified stage.

2.3 Definition of maturational sub-stages

After defining one stage for each portion of the MPS, a new definition of stages was elaborated, considering differences in MPS maturation in the maxillary and palatine bone.

The modification of the evaluation method of MPS maturational stages required that, for a stage to be considered B or C, it should be classified as such in at least 4/5 of the MPS. If it was 2/5 and 3/5 in stages B or C in the same MPS, we classified as maturational sub-stage C-, independently of the anteroposterior order. Sub-stage C- was considered transitional between stages B and C. Also, a sub-stage C+ was defined. This was designated when three maxillary portions were classified as stage C, the anterior portion of the palatine bone was stage C and the posterior portion of the palatine bone stage D, i.e., without suture visualization. Therefore, sub-stage C+ was considered transitional between stages C and D. Stage D requires stage C throughout the maxillary bone, without suture visualization in the palatine bone. Figure 2 shows the maturational stages considered in the present study, contemplating the proposed methodological variation of the evaluation of MPS morphology.

Figure 2 - Axial slices demonstrating the maturational stages of MPS, as follows: stage B (I); sub-stage C- (II); stage C (III); sub-stage C+ (IV); and stage D (V)



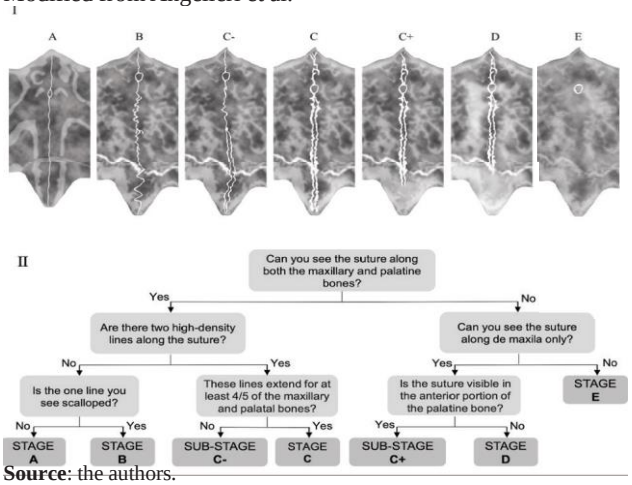
Source: the authors.

It was defined a new ground truth for the 158 images included in the sample, considering stages B, C and D, as well as the sub-stages C- and C+.

2.4 Validation of the modified classification of MPS maturational stages

Two new examiners (V.M.L and L.F.T.M) were trained by the principal investigator using 10 illustrative images of the C- and C+ sub-stages. In addition, they were given a description of the stages, flowchart and schematic drawings, both modified from Angelieri et al. [18] (Figure 3) to aid in the new classification, as follow: Stage B (Stage B in al least 4/5 of the suture in the maxillary and palatine bones); Stage C- (stages B and C, alternating or not, in 2/5 or 3/5 of the suture in the maxillary and palatine bones); Stage C (stage C in al least 4/5 of the suture in the maxillary and palatine bones); Stage C+ (stage C throughout the maxillary bone and visualization of the suture only in the anterior portion of the palatine bone) and Stage D (stage C throughout the maxillary bone without visualization of the suture only in the palatine bone).

Figure 3 - Schematic drawing (I) and Fluxogram (II), illustrating the proposed modification of the MPS maturation stages. Modified from Angelieri et al.[18]



Source: the authors.

The principal investigator divided the 158 CBCTs into three groups of images (53, 53 and 52) that were evaluated at 1-day intervals by the examiners and then compared for inter-examiner agreement. High resolution images were randomly inserted into a PowerPoint 2016 presentation (Microsoft, Redmond, WA, USA) with a black background, without any identification of the maturational stage or patient data.

2.5 Evaluation of method error

To verify the reliability of the MPS classification method, evaluation of 48 CT scans was repeated by one evaluator (L.F.T.M) 15 days after the first evaluation (intra-examiner agreement). Measurement agreement was evaluated by the weighted kappa coefficient[22] and the result was interpreted according to Landis & Koch.[23]

2.6 Statistical analysis

Intra- and inter-examiner agreements were expressed as weighted kappa coefficients with 95% confidence intervals. The data were described in tables and graphs as absolute (n) and relative frequency (%). The chi-square test was used to compare the groups. In all statistical tests, a significance level of 5% was adopted. All statistical analyses were performed on Statistica program 13 (StatSoft Inc., Tulsa, USA).

3 Results and Discussion

The weighted kappa values for inter-examiner evaluation was 0.54 for examiner 1, and 0.53 for examiner 2, both considered "moderate". Intra-examiner evaluation returned a weighted kappa value of 0.7, considered "substantial".

Table 1 displays the distribution of maturational stages and sub-stages by age group and gender. In the 11-15y group, stage B and sub-stage C- had similar prevalence and Stage C was the most prevalent, including 32 individuals (43.2%). In the 16-20y group, the prevalence of sub-stages was reversed, with C- represented by 7 individuals and C+ by 10 individuals, both without gender dimorphism. Stage C remained dominant, represented by 38 individuals (45.2%). (if the stage C was predominat, why the subclassification)? ANSWER: dear reviewer, the subclassification was designed to reduce the prevalence of stage C and improve diagnosis. As discussed in the following paragraphs, stage C has an inaccurate diagnosis. On the other hand, the substages show signals which allows to do a better prognosis. Such information was added in Introduction as well.

Table 1 - Description of the classifications by age group and gender

Age group	Gender	Sub-stage Classification										Total	
		B		C-		C		C+		D			
		n	%	n	%	n	%	n	%	n	%	n	%
11-15y	Female	8	20.0	3	7.5	21	52.5	2	5.0	6	15.0	40	100
	Male	8	23.5	9	26.5	11	32.4	2	5.9	4	11.8	34	100
	Female + Male	16	21.6	12	16.2	32	43.2	4	5.4	10	13.5	74	100
16-20y	Female	4	8.5	4	8.5	23	48.9	4	8.5	12	25.5	47	100
	Male	3	8.1	3	8.1	15	40.5	6	16.2	10	27.0	37	100
	Female + Male	7	8.3	7	8.3	38	45.2	10	11.9	22	26.2	84	100
11-20y	Female	12	13.8	7	8.0	44	50.6	6	6.9	18	20.7	87	100
	Male	11	15.5	12	16.9	26	36.6	8	11.3	14	19.7	71	100
	Female + Male	23	14.6	19	12.0	70	44.3	14	8.9	32	20.3	158	100

Source: resource data.

According to table 2, comparison between gender in MPS maturation stages was not statistically significant (p= 0.267). Prevalence of the MPS maturational stages between age groups demonstrated that Stages B and D had statistically significant differences between the groups.

Table 2 - Comparison among age groups and gender (in the 11-20 age group) in each Sub-stage classification (Chi-square test)

Age group	Sub-stage Classification										Total
	B*		C-		C		C+		D*		
	n	%	n	%	n	%	n	%	n	%	
11-15y	16	21.6	12	16.2	32	43.2	4	5.4	10	13.5	74
16-20y	7	8.3	7	8.3	38	45.2	10	11.9	22	26.2	84
Gender											
Female	12	13.8	7	8.0	44	50.6	6	6.9	18	20.7	87
Male	11	15.5	12	16.9	26	36.6	8	11.3	14	19.7	71

Chi-square test for age groups: p = 0.019. * Sub-stage classifications with statistically significant difference among age groups. Chi-square test for gender: p= 0.267ns.

Source: resource data.

From the 158 MPS maturational stages analyzed, 33 (20.9%) changed to the new sub-stages, distributed as 19 in sub-stage C- and 14 in sub-stage C+. Table 3 shows that in 11-20y, 20.7% of those who had been previously classified as stage B were re-classified as sub-stage C-. Those previously classified as stage C, 23.9% had their classification changed: 14.1% to sub-stage C- and 9.8% to sub-stage C+. Those who were previously classified as stage D, 13.5% were re-classified as sub-stage C+.

Table 3 - Comparison of the classification without sub-stages to classification with sub-stages

Age group	Stage	Classification with sub-stages										Total
		B		C-		C		C+		D		
		n	%	n	%	n	%	n	%	n	%	
11-15y	B	16	76.2	5	23.8	0	0.0	0	0.0	0	0.0	21
	C	0	0.0	7	16.7	32	76.2	3	7.1	0	0.0	42
	D	0	0,0	0	0.0	0	0.0	1	9.1	10	90.9	11
16-20y	B	7	87.5	1	12.5	0	0.0	0	0.0	0	0.0	8
	C	0	0.0	6	12.0	38	76.0	6	12.0	0	0.0	50
	D	0	0.0	0	0.0	0	0.0	4	15.4	22	84.6	26

Age group	Stage	Classification with sub-stages										Total
		B		C-		C		C+		D		
		n	%	n	%	n	%	n	%	n	%	
11-20y	B	23	79.3	6	20.7	0	0.0	0	0.0	0	0.0	29
	C	0	0.0	13	14.1	70	76.1	9	9.8	0	0.0	92
	D	0	0.0	0	0.0	0	0.0	5	13.5	32	86.5	37

Highlights where classification changes occurred.
Source: resource data.

From the previously classified as stage B, five individuals changed to sub-stage C- in the 11-15y group, and only one individual to the 16-20y group. None changed to sub-stage C+, independent of the age group evaluated. Twenty-two individuals previously classified as stage C had their classification changed: 13 individuals changed to sub-stage C- and nine to sub-stage C+. Stage D, by contrast, had none of individuals changing to sub-stage C-, but added one individual to sub-stage C+ from the 11-15y group and four from the 16-20y group.

The high prevalence of stage C from 11 to 15 years[19] and from 16 to 20 years[21] does not allow prediction of the quality of RME during a critical period, when most patients seek orthodontic treatment. There is a need to identify possible maturation variants among individuals in this maturational stage, because there is a clear incongruity in the orthodontic literature between the quality of understanding of the RME process[1-7,16,17] and the ability to predict it.[18,19,21]

In the present study, examiners carefully evaluated 158 CBCTs of patients aged 11 to 15 years and 16 to 20 years classified previously as being in intermediate stage C, as well as the adjacent stages, B and D. The methodology divided the MPS into six portions, each portion being classified as proposed by Angelieri et al.[18] It is known that the maturation process occurs from posterior to anterior,[9] and logic would indicate the MPS would mature earlier in the most posterior areas than in more anterior areas. Although it frequently presents itself this way, MPS in the most anterior area did not show consistent pattern and, therefore, it was not included in the final definition of the maturational stage. The method of acquisition of the slices, especially in curved palates, generates a great deal of variation in height between the slices in the premaxilla, explaining the absence of a consistent pattern.

After methodological definition, MPS maturational differences were found in relation to the previously established stages (B, C and D), leading to the elaboration of two new sub-stages: sub-stage C- was considered transitional between stages B and C, and sub-stage C+ was considered transitional between stages C and D. Tables 1 and 2 illustrate the new distribution obtained, considering sub-stages. Although statistical differences between the age groups were present only for the B and D stages, sub-stages C- and C+ showed consistent differences between the groups evaluated. The prevalence of incipient stages (B and C-) was 37.8% in the 11-15y group and only 16.6% in the 16-20y group, whereas the stages with sutural fusion (C+ and D) represented 18.9% in the 11-15y group, rising up to 38.1% in the 16-20y group. These data allow us to speculate as to differences in the prognosis of RME for these sub-stages, elucidating cases previously established as being at the same stage of maturation. The present study corroborated the higher prevalence of stage C found in previous studies,[18,19,21] but it decreased its prevalence and allowed a better understanding of the process of maturational evolution of the MPS when presenting sub-stages. We argue here that morphological differences of MPS, previously defined as belonging to the same stage and therefore having the same prognosis, may be important enough to alter the possibility of clinical success of RME. In recent study, Isner et al [24] alerts to the predictive inconsistency of the effects of RME through the method of evaluation the MPS maturational stages. This finding may be related to the actual deficiency of the method or, perhaps, reinforce the need to revisit the stages initially proposed by Angelieri et al.,[18] seeking a greater correlation between the evaluation of MPS maturation through CBCT and the clinical results of the ERM.

Sub-stage C- presents fewer “islets and/or two-line areas” compared to stage C and, because it is transitional between stages B and C, it probably has good prognosis for RME. An interesting finding was the presence of sutural fusion in the posterior part of the palatine bone in 14 individuals (sub-stage C+). We believe that good prognosis for RME in this sub-stage is restricted to cases where the intention is to open the anterior region of the arch using a butterfly expander, because the resistance in the posterior region is probably similar to that of stage D. The need for a large transversal maxillary gain for patients classified as sub-stage C+ and stage D would indicate more invasive therapies, either implant supported (MARPE) or surgically assisted (SARPE). Except for sub-stage C+ and stage D, the 11-15y group demonstrated a decreasing prevalence as the maturational stage evolved, while the 16-20y group had a growing prevalence (Table 3). This distribution demonstrated the representativeness of each stage in the two age groups, and corroborated data found in previous studies,[18-21] where there was a higher incidence of incipient stages at early ages and more advanced stages at older ages. The composition of the sub-stages C- and C+ by patients previously classified as stages B and D reinforces the differences found in the two age groups. No patient previously classified as stage B was reclassified as C+. Similarly, no patient previously classified as stage D was reclassified as C-.

Stage C contributed the most to the new classifications, with 13 individuals being reclassified to sub-stage C- and nine to sub-stage C+.Do these 22 individuals, previously classified as stage C, have the same prognosis for RME? ANSWER: Dear reviewer, we expect differente prognosis for sub-stages when compared to stage C. This happens because in C- there is less bone island while in stage C+ there is an more advanced bone fusion in the palatine bone as discussed in the 4th paragraph.

It is recognized that other factors such as the resistance of the circumaxillary sutures[6,25-28] exerts an important influence on the transverse orthopedic management of the maxilla. The maturational assessment by computed tomography to other sutures has already occurred. [29,30] However, MPS plays a relevant role in this process. In a recent study, Ok et al. [30] evaluated the MPS and the zygomaticomaxillary suture maturation, and the closure degree of the spheno-occipital synchondrosis in patients of different age groups. They concluded that there is a simultaneous progress in the maturation of these structures. [30] It´s easier to identify the maturation of the MPS when compared to other craniofacial sutures. Thus, seems reasonable to elect the MPS as a reference of circumaxillary suture maturation.

Therefore, it was considered that the definitive elucidation of MPS maturation process should play a prominent role. Unlike the well-established orthopedic and orthodontic effects of RME, the prognosis for this therapy remains a challenge. The study of MPS by the method proposed here alerts for the presence of new maturational stages. There is a need for a greater correlation between the maturational stages of MPS, evaluated by means of CBCT, and the effects of RME. Clinical studies are necessary to validate the methodology proposed.

4 Conclusion

The redefinition and validation of the maturational stages of MPS, considering the sub-stages C- and C+, may allow to elucidate the difference in the prognosis of RME among individuals aged 11 to 20 years. The prevalence of 37.8% of incipient stages (B and C-) in 11-15y group, compared to the stages with sutural fusion (18.9%), indicates a good prognosis of RME for this age group. On the other hand, the prevalence of 38.1% of stages with sutural fusion (C+ and D) in 16-20y group, compared to incipient stages (16.6%), indicates a doubtful prognosis of RME for this age group. A clinical study is still necessary in order to confirm the hypotheses presented.

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