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original article

Association of the mid-palatal suture morphology to the age and to its density: A CBCT retrospective comparative observational study

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Summary

Objective > The twofold aim of the present investigation was to: 1. evaluate the degree of mid-palatal suture (MPS) maturation via CBCT in relation to patient age, and 2. to determine whether there was a correlation between quantitative (i.e., suture density) and qualitative (i.e., suture morphology) analysis.
Materials and methods > The stage of mid-palatal suture maturation and suture density ratio were assessed for 160 subjects on CBCTs using five qualitative stages proposed by Angelieri with the addition of three additional stages (i.e., B/C, C/D and D/E) and quantitative grey density scores of Grünheid MPS1,2,3,4 with the addition of parasutural bone and soft palate. The repeatability of both methods was evaluated using Cohen's K.The relationship between midpalatal suture maturation and age was assessed using ANOVA and Classification and Regression Trees (CART) analysis and tabulation and a χ^2 test for quantitative and qualitative analysis respectively. Statistical significance was assessed using a 5% threshold.
Results > The final sample included 160 CBCTs (80 male,80 female; mean age 23.2 $\pm$ 13.5). Both methods were found to be correlated and highly repeatable. In addiction they showed an age-related correlation in MPS morphology.

[1] For the author Giorgio Alfredo Spedicato, there is a disclaimer: "The views and opinions expressed in this article are those of the author's and do not necessarily reflect the position of the organization of which he is part''.

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Conclusion > The mid-palatal suture density ratio and the stage of mid-palatal suture maturation has the potential to become useful in clinical practice. In fact, despite the correlation between MPS maturation stage and age, the latter parameter cannot be used as a clinical discriminator due to the great variability between subjects. It is therefore advisable to assess each patient individually on CBCT scans in order to determine treatment choices.

Introduction

Maxillary expansion by means of mid-palatal suture (MPS) opening was first performed in the late 1800s [1], and nowadays, rapid maxillary expansion (RME) is a procedure commonly used to correct transverse skeletal deficit in growing patients [2]. However, due to a combination of circum-maxillary resistance and dental anchorage, this provokes dentoalveolar, as well as skeletal effects, which range from 6% to 49% of the total expansion [3,4]. This has many unwanted effects, including fenestration of the vestibular cortical bone, loss of periodontal attachment, root resorption, and instability of the expansion achieved [5–7].

In adults there is a greater risk of these complications due to the greater resistance offered by the circum-maxillary sutures. Hence, routine use of RME has conventionally been limited to growing patients, and when the sutures present a high degree of interdigitation, it is opportune to resort to skeletal anchorage devices [8,9], or even surgery in some cases, thereby increasing the cost and risks to the patient [10].

The great variability in MPS interdigitation reported in several studies [11,12] indicates that the choice between traditional and surgically assisted expansion cannot be made on the basis of patient age alone, as unfused sutures have been found in patients of up to 71 years of age [11]. Confirming this aspect, there is no clear indication of the timing of surgically assisted expansion, and studies have proposed a wide variety of age cut-offs [13,14].

As an alternative to patient age, authors have suggested selection methods aimed at evaluating the degree of maturation of the MPS on two-dimensional (occlusal radiographs) and volumetric scans, the latter thanks to the introduction of cone-beam computed tomography (CBCT) [15–19], which offers undisputed diagnostic advantages with respect to traditional imaging techniques, enabling both qualitative and quantitative assessment [20,21].

Within these premises, this study evaluated the degree of maturation of the MPS. The twofold aim was to: 1. evaluate the degree of mid-palatal suture (MPS) maturation via CBCT in relation to patient age, and 2. to determine whether there was a correlation between quantitative (i.e., suture density) and qualitative (i.e., suture morphology) analysis.

Materials and methods

In order to assess MPS maturation, a sample of CBCT scans from 160 patients (80 males, 80 females; mean age 23.2 ± 13.5), previously performed for medical reasons, was selected.

CBCT scans were excluded from the study for the following reasons:

- craniofacial syndromes;
- idiopathic osteosclerosis;
- previous orthodontic treatment;
- previous orthognathic surgery;
- cleft jaw and/or jaw atrophy;
- generalised joint pathologies;

High resolution (HiRes) CBCT scans were taken on a NewTom VGI Evo scanner with a 12 × 8 field of view (FOV), slice thickness 0.150 mm, and scan time of 4.3 s. Each scan was anonymized to prevent knowledge of demographic variables conditioning the examiner's findings, and orientation was performed according to the method proposed by Angelieri et al. [15].

NNT software (NewTom, Italy) was used to perform the analysis, in which MPS maturation was evaluated according to the following parameters:

Qualitative assessment

This was conducted by a dentist regarding the classification proposed by Angelieri et al. [22].

Stage A, straight high-density sutural line, with no or little interdigitation.

Stage B, scalloped appearance of the high-density sutural line.

Stage C, 2 parallel, scalloped, high-density lines that were close to each other, separated in some areas by small low-density spaces.

Stage D, fusion completed in the palatine bone, with no evidence of a suture.

Stage E, fusion anteriorly in the maxilla.

However, during the assessment we identified intermediate stages to those proposed, and we therefore added the further stages B/C, C/D and D/E, classifying MPS maturation into 8 stages based on MPS morphology. In the event that the suture had intermediate characteristics the most matured stage was considered.

Quantitative assessment

This analysis was inspired by Grünheid et al. [16]. Specifically, the mean grey density was determined for the following regions of the suture, starting from the most distal point of the incisal foramen:

- MPS_1: rectangle of pre-established dimensions (6 × 12 mm) centred on the MPS (*figure.1a*).
- MPS_2: rectangle containing the portion of the suture that extends to the intersection of the transverse palatal suture (*figure 1b*)

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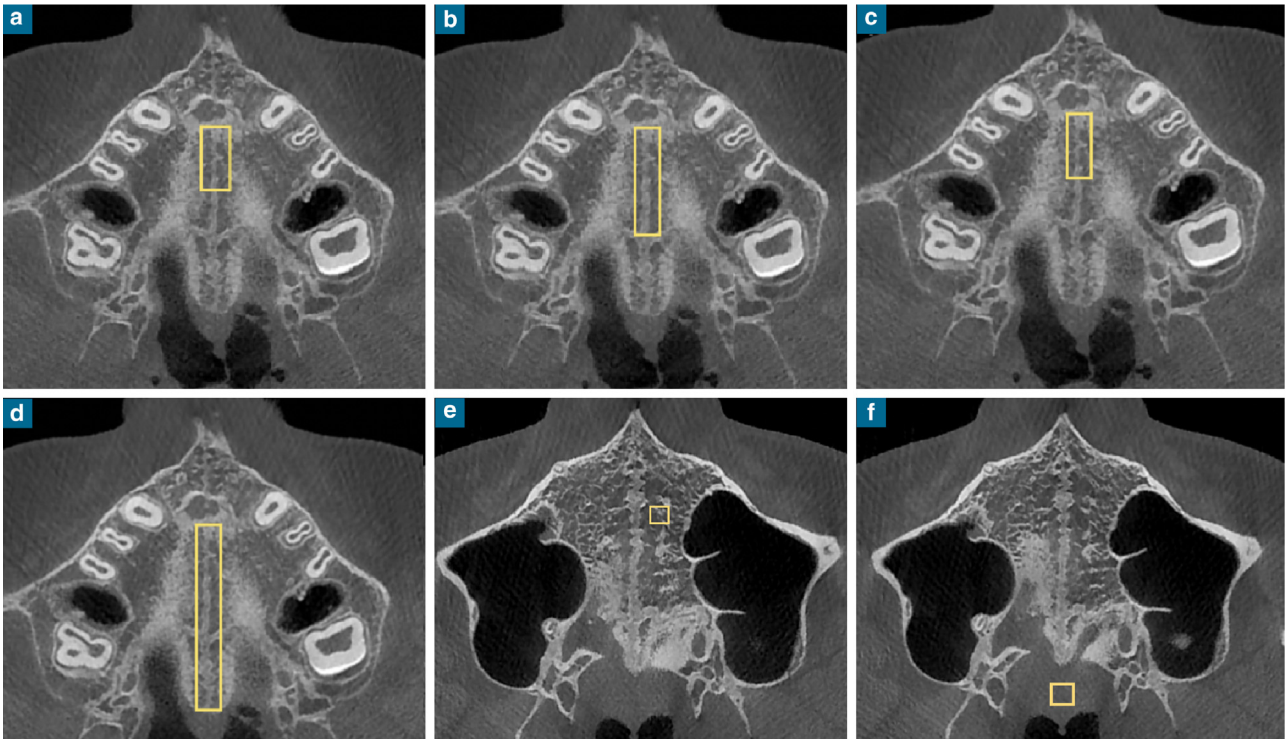

FIGURE 1

a-d: Mid-palatal suture (MPS) maturation region delineated by a rectangle:a: of pre-established dimensions (6 × 12 mm) centred on the MPS, (MPS1); b: delineated by a rectangle containing the portion of the MPS that extends to its intersection with the transverse palatal suture, (MPS2); c: delineated by a rectangle containing the portion of the MPS that extends to the mesial margin of the first permanent molar, (MPS3); d: delineated by a rectangle containing the entire MPS, (MPS4); e-f. Mean density of the parasutural bone (PB) and soft tissue at the soft palate (SP) investigated using a square of pre-established dimensions (4 × 4 mm): e: PB; f: SP.

- MPS_3: rectangle containing the portion of the MPS that extends to the mesial margin of the permanent first molar (*figure 1c*)
- MPS_4: rectangle containing the entire length of the MPS (*figure 1d*)

The following regions were also assessed:

- PB:square of pre-established dimensions (4 × 4 mm) at the parasutural bone (*figure 1e*);
- SP:square of pre-established dimensions (4 × 4 mm) containing the soft tissues of the soft palate (*figure 1f*).

Quantitative analysis of the relationship between the different MPS sections examined. Correlations between the quantitative and qualitative analyses. Correlations with demographic variables (sex and age). For this purpose, the total sample was subdivided into 4 age groups:

- 7–11 (23 male, 17 female; mean age 10 ± 1.6);
- 12–17 (18 male, 22 female; mean age 14.6 ± 1.9);
- 18–29 (21 male, 19 female; mean age 24.2 ± 4.1);
- >30 (17 male, 23 female; mean age 43.8 ± 5.6).

In order to test the repeatability of the methods, all parameters were evaluated at baseline (T0) and 60 days after the first analysis (T1), in a sample of 40 subjects chosen at random by an external examiner.

The research protocol was approved by the Institutional Review Board of the University of Ferrara Postgraduate School of Orthodontics, Ferrara, Italy (n. FUPSO372020).

Statistical analysis

The repeatability of categorical measures was assessed using Cohen K metrics (K) using the "squared" distance approach to allow for the ordinal nature of the ratings. The statistical association between the objective measures was tested using a Principal Component Analysis; the first principal component was then used to obtain a synthetic score ("GreyScore") that synthesizes the objective measures using factorial analysis scores. The score is on a standardized scale (mean 0, sdt 1).

The relationships between GreyScore and both qualitative analysis and patients' demographic variables (gender and age) were assessed by ANOVA and Classification and Regression Trees (CART) analysis. The association between the morphological staging and age group was then analysed using a cross-

TABLE I
Descriptive statistics pertaining to the parameters. MPS_1: rectangle of pre-established.

Parameters	Num	Mean	SD
MPS_1	142	682.96	202.13
MPS_2	142	701.69	187.81
MPS_3	50	608.31	170.28
MPS_4	142	725.60	176.63
PB	142	795.84	300.56
SP	141	104.54	120.35

Dimensions (6 × 12 mm) centred on the midpalatal suture; MPS_2: rectangle containing the portion of the suture that extends to the intersection of the transverse palatal suture; MPS_3: rectangle containing the portion of the MPS that extends to the mesial margin of the permanent first molar; MPS_4: rectangle containing the entire length of the midpalatal suture; PB: square of pre-established dimensions (4 × 4 mm) at the parasutural bone; SP: square of pre-established dimensions (4 × 4 mm) containing the soft tissues of the soft palate.

tabulation and a χ^2 test (using the Montecarlo approach to obtain the p-value).

Statistical procedures were performed using R statistical software, and the level of significance was set at $P < 0.05$.

Results

Descriptive statistics for each outcome variable are presented in *table I*.

The results of both the qualitative (Kappa coefficient = 0.827) and quantitative evaluations (*table II*) reveal a strong agreement between the stages identified at the baseline and after a

TABLE III
Factor loading of one factor analysis solutions (at one factor).

Loadings	
	MR1
MPS_1	0.954
MPS_2	0.981
MPS_3	0.850
MPS_4	0.924
SP	0.323
PB	0.730
	MR1
SS loadings	4.086
Proportion Var	0.681

MPS_1: rectangle of pre-established dimensions (6 × 12 mm) centred on midpalatal suture; MPS_2: rectangle containing the portion of the suture extending to its intersection with the transverse palatal suture; MPS_3: rectangle containing the portion of the suture extending to the mesial margin of the first permanent molar; MPS_4: rectangle containing the entire length of the MPS; PB: square of pre-established dimensions (4 × 4 mm) at the parasutural bone; SP: square of pre-established dimensions (4 × 4 mm) containing an area of soft tissue at the soft palate

TABLE IV
One way ANOVA.

	Df	Sum of squares	Mean squares	F value	Pr (>f)
Stage	7	62.3120	8.90172	15.1079	0.000000000000020047
Residuals	133	78.3647	0.58921		

TABLE II
Repeatability analysis, continuous scores.

Measure	t_stat	t_pvalue	Dahlberg	ccc.test	ccc.lci	ccc.uci
MPS_1	0.07	0.94	125.59	1.00	0.99	1.00
MPS_2	0.02	0.99	57.95	1.00	0.99	1.00
MPS_3	−0.30	0.77	832.13	0.97	0.90	0.99
MPS_4	−0.06	0.96	56.64	1.00	0.99	1.00
SP	0.07	0.95	49.69	1.00	0.99	1.00
PB	0.09	0.93	3676.27	0.92	0.75	0.98

MPS_1: rectangle of pre-established dimensions (6 × 12 mm) centred on midpalatal suture; MPS_2: rectangle containing the portion of the suture extending to its intersection with the transverse palatal suture; MPS_3: rectangle containing the portion of the suture extending to the mesial margin of the first permanent molar; MPS_4: rectangle containing the entire length of the MPS; PB: square of pre-established dimensions (4 × 4 mm) at the parasutural bone; SP: square of pre-established dimensions (4 × 4 mm) containing an area of soft tissue at the soft palate; t_stat = t test; t_pvalue = test *P*-value; ccc= intraclass correlation coefficient; lci = lower confidence interval; uci = upper confidence interval

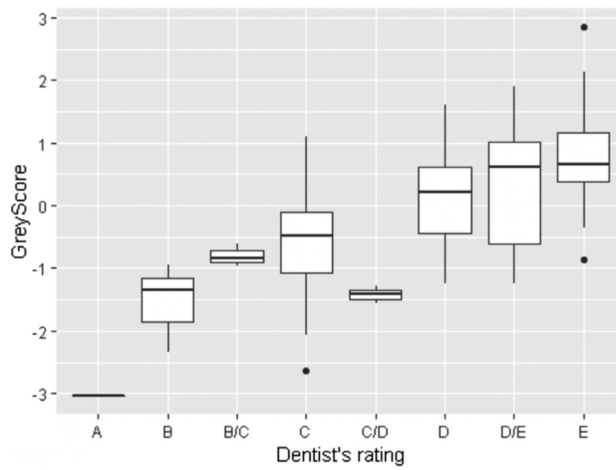

FIGURE 2

Box-plot showing the relationship between the synthetic "GreyScore" and the qualitative assessment stages A–E.

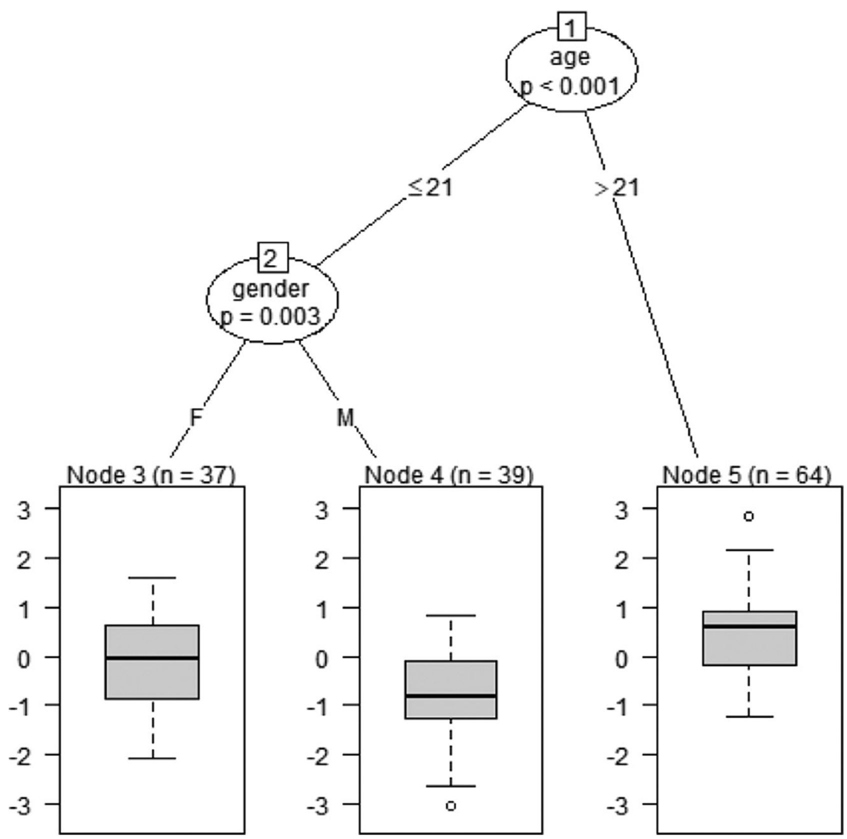

FIGURE 3

CART analysis of the age and gender variables

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Table V
Distribution of stages by age group, expressed as a percentage.

Group	A	B	B/C	C	C/D	D	D/E	E
7–11	2.9	2.9	5.9	61.8	2.9	11.8	0.0	11.8
12–17	0.0	4.7	0.0	34.9	2.3	25.6	7.0	25.6
18–29	0.0	0.0	0.0	37.8	0.0	21.6	5.4	35.1
>30	0.0	0.0	2.2	17.4	0.0	17.4	10.9	52.2

X^2 statistic 41.073997471, *P*-value = 0.003998001

washout period of 60 days, thereby confirming the repeatability of the methods used.

The *table III* shows the factor loading between the original variables and the first principal component (then named "Grey-Score'') and the portion of total-variance explained by this factor. The association between the different MPS measurements shows how a single factor reproduces most of the variability of objective measures (about 68%). The solutions deriving from the one-factor analysis show that all original variables strongly positively correlate with the GreyScore, with the exception of "density up to the molar'' whose association is moderate weight (*table III*).

The GreyScore included all the MPS measurements made (excluding the PB and SP variables, since they are not representative of the MPS). The MPS_3 variable was omitted from the factor score extraction due to the lack of assessable values in most tests. Nonetheless, the ANOVA one-way analysis of the relationship between the GreyScore and the qualitative stage assessment revealed a significant monotonic trend (as the p-value in *table IV* indicates), as illustrated in *figure 2*, indicating that an increase in density at the MPS corresponds to an increase in the stage identified by the morphological evaluation.

CART analysis (*figure 3*), performed to investigate the association between GreyScore and demographic variables, revealed that patients aged above 21 generally display a higher Grey-Score. Also, males in the group aged 20 or lower tended to show lower GreyScores.

As shown in *table V* the distribution of the stages in the different age ranges reveals a statistically significant relationship between maturity stage and age (χ^2 statistic 41.073997471, *P*-value = 0.003). Specifically, stage A was only detected in the 7–11 age group, while stage B only occurred in patients of up to a maximum age of 17 years; stage C was the most frequently detected in the groups of subjects aged 7–11, 12–17 and 18–29 years, with respective percentages of 61.8%, 34.9% and 37.8%, while stage E occurred in all groups, but its frequency increased with increasing age.

Discussion

Although orthodontic treatment planning to correct maxillary skeletal deficit has traditionally been guided by the patient's age [22], there is, in fact, no consensus regarding the cut-off age for conventional vs surgical expansion [13,14]; this reflects the lack of correlation between MPS maturation and the chronological age of the patient.

Since the centres of resistance to skeletal expansion of the upper jaw are found at the level of the circum-maxillary sutures, in particular the MPS [21], several studies have investigated the degree of maturation of the latter [15–17]. Nevertheless, with except for a single study, which did not, however, consider patient age [16], this is the first time that the correspondence between subjective and objective methods has been evaluated and compared with patients' demographic variables.

We first set out to evaluate the degree of maturation of the MPS on CBCT through both qualitative and quantitative analysis and then to relate this to patient age. Having ascertained the

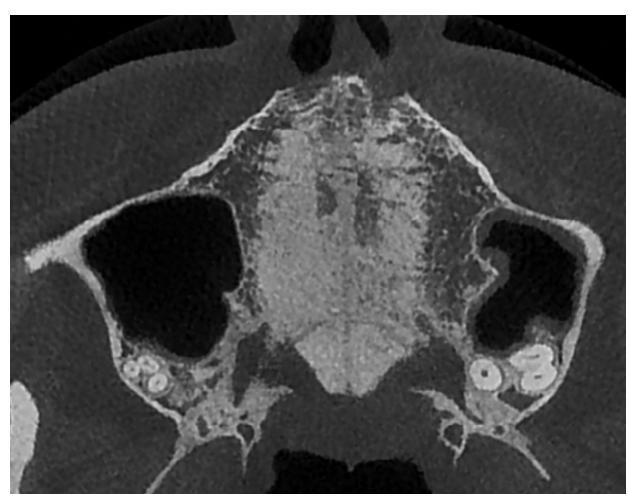

Figure 4
Stage D/E of the MPS maturation stages observed

repeatability of both methods, we also investigated whether there exists a correlation between the MPS assessment methods and the different MPS sections we considered. In line with previous reports [16,21,22], both qualitative (K = 0.827) and quantitative evaluation demonstrated excellent repeatability. Regarding the morphological analysis, we began with the A–E method proposed by Angelieri et al. [15], but identified three intermediate stages concerning the original classification, namely B/C, C/D and D/E; patients classified as such displayed intermediate characteristics, between two reference stages, exhibiting morphological features similar to both. For example, about the D/E stage (*figure 4*) the fusion of the suture is evident in the middle of the maxillary bone, but is not complete as it is in stage E, while in the most anterior region the morphology remains similar to stages C and D. This too, is in line with recent findings, specifically those by Haghanifar et al. [23], who also proposed the inclusion of an intermediate C/D stage.

Assessing suture morphology is a subjective method and therefore requires complex training. To overcome these limitations, several authors have proposed objective methods based on bone density for evaluating MPS maturation on CBCT scans [16,17]. We too used CBCT scans to objectively determine the average density values at defined regions of the MPS, the parasutural bone and soft tissue. We then analysed the association between the various MPS measurements using PCA analysis, which showed that the different regions of interest (ROIs), MPS1-4, had comparable average density values, and could therefore be summarized by a single factor called the "GreyScore". It follows that in clinical settings, just the most easily identifiable ROI could be used for morphological assessment purposes, as representative of the others. Based on our findings, this would be MPS_2, a rectangle comprising the portion of the suture that extends to the intersection of the transverse palatal suture, since it is based on two well-defined landmarks, meaning that the identified region would always include the same portion of the suture, regardless of the size of the subject's maxilla. According to our findings, there was a clear association between this objective method of morphological assessment and the subjective A–E method, as the GreyScore, and therefore the density, increased with greater interdigitation (*figure 2*). Furthermore, both methods showed a correlation with patient age. Specifically:

CART analysis of the quantitative assessment results revealed that patients of over 21 years of age generally present a greater bone density, and that bone density in subjects aged under 21 is lower in males than in females (*figure 3*).

The results of the subjective analysis showed a statistically significant correlation (p = 0.003) with chronological age; however, some young subjects presented advanced maturation stages, while some adult subjects, albeit to a lesser extent, presented an MPS with incomplete fusion. In particular, in the group of subjects under the age of 11, stage C occurred more frequently than the others (61.8%), as it did in the 12–17 age group (34.9%), but there were also high percentages of stages D and E (25.6% in both cases). In the 18–29-year age range, stages C and E presented with similar percentages, 37.8% and 35.1%, while in the age group including subjects over the age of 30, stage E was identified in 52.2% of cases.

There is conflicting data on MPS maturation in the literature as regards to its relationships with both chronological age [11,17,18,24–26] and gender [11,18,25]. That being said, our results are in line with those reported by Ladewing et al. [25], who found that over 90% of subjects between the ages of 16 and 20 were in stages C, D and E, which we showed was also true in patients aged 12 to 17. As regards to subjects over the age of 18, our findings are in line with those reported by Angelieri et al. [19], i.e., that most subjects between the ages of 18 and 66 present stages D and E, but that 12% have sutures that are not completely fused. It is difficult to compare findings on subjects under the age of 11, as there is a lack of data pertaining to this age range. Similarly, it is not feasible to compare our densiometric values (GreyScore), as it is not meaningful to directly compare the density values obtained using different CBCT scanners [17].

The potential advantages of using this strategy in the clinical fields are quite intuitive; indeed, our results show a variation in the degree of ossification of MPS suggesting that an individualized diagnosis could offer advantages in clinical and economic terms [5,6,10] during treatment planning for correcting the skeletal deficit in the upper jaw. Although there is a tendency for interdigitation to increase with age, there is considerable inter-individual variation, and cannot therefore be considered the criterion of choice.

It is important to point out that, as suggested by the literature [27], the morphology on the radiographic image can differ from the actual structure of the mid-palatal suture itself. On the other hand, other structures are involved in the skeletal expansion of the maxilla (i.e., zygomaticotemporal suture, zygomaticofrontal suture, and zygomaticomaxillary suture) and should therefore be considered in future studies [22].

Conclusions

Both the quantitative and qualitive assessments proved to be highly repeatable.

There was negligible difference between the various investigated regions of the MPS, indicating that only one need be evaluated for clinical purposes.

There was a close correlation between the quantitative and qualitative method, both indicating an increasing bone density from stages A to E.

Both types of assessment revealed a correlation with age, but this cannot be used as a discriminating factor, as a subgroup of growing subjects presented advanced stages in which the MPS appears completely fused, and vice versa, some adults of over

30 years of age presented sutures that were not completely fused.

Disclosure of interest: The authors declare that they have no competing interest.

Author Contributions: AC performed the study and wrote a first draft of the article.
SC helped AC to perform the study.
FS conceptualized the investigation.
GAS performed the statistical analysis.
LL supervised the investigation and revised the manuscript

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