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# Midpalatal Suture Density CBCT Evaluation, sex gender and growth pattern related variability in 392 adolescents treated with Rapid Maxillary Expander appliance

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## Abstract

**Background and objectives.** The aim of this paper was to evaluate the changes in the mean bone density values of the midpalatal suture in 392 young patients treated with the Rapid Palatal Expander appliance according to sex, gender, vertical and sagittal skeletal patterns.

**Materials and Methods.** The evaluations were performed using the low-dose protocol cone-beam computed tomography scans at t0 (preoperatively) and t1 (1 year after the beginning of the therapy). The region of interest was used to calculate bone density in Hounsfield units (HU) in the area between the maxillary incisors.

***Results.*** CBCT scan data of 196 females and 196 males (mean age of 11,7 years) showed homogeneous and similar density values of the MPS at T0 (547.59 HU - 565.85 HU) and T1 (542.31 - 554.20 HU). Class III skeletal individuals showed a significant higher BD than the II class group at T0, but not at T1.
Females showed significantly higher BD than males at t0 and t1. No significant differences were found between the other groups and between two-time points in terms of bone density values of the MPS.

***Conclusions.*** Females and III class groups showed significantly higher bone density values than males and II class, respectively. No statistically significant differences were found from T0 to T1 in any groups, suggesting that a similar rate of suture reorganization occurs after the use of the RPE, following reorganization and bone deposition along with the MPS.

*Keywords: rapid palatal expander; midpalatal suture; bone density; cone-beam computed tomography, facial patterns, skeletal growth pattern.*

## Introduction

The present paper aims to measure mean bone density (BD) values of the midpalatal suture (MPS) in order to predict an accurate estimation of the MPS response to expansion therapy with Rapid Palatal Expander (RPE) appliance as related to sex gender (males and females), vertical skeletal patterns (hypodivergent, normodivergent, hyperdivergent) and sagittal skeletal patterns (I class, II class, III class).
Maxillary transverse deficiency (MTD or maxillary hypoplasia) is a common problem that affects the normal development of the maxillofacial complex. Therefore, early diagnosis and correction of MTD are essential to achieve a normal transverse skeletal relationship between maxilla and mandible.
The incidence of MTD ranges from 8.5 to 22% [1] in children and adolescents. MTD is usually associated with unilateral or bilateral crossbite [2], generalized lack of space in the maxillary arch and crowding because the jaw is narrow compared with the rest of the craniofacial structures. These conditions can be treated using

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RPE as described by Angell in 1860 [3]. RPE appliance is indicated in growing patients because the MPS fusion occurs at 17 years, as reported by Björk [4]. In terms of sex-gender, the mean age of ossification of the MPS in girls is 16 years and in boys 18 years, as described by Melsen [5].
The maturation stages of the MPS are not directly related to chronological age, as reported in numerous studies [6, 7]. The hand and wrist method (HWM) [6] and cervical vertebrae method (CVM) [7] are the conventional indexes chosen to determine the possibility of maxillary expansion. In 2013, Angelieri [8] introduced a new index by observing CBCT images and suggested that maturation of the MPS can be classified into five stages (A, B, C, D, E). There are three types of MPS disjunction: RPE (with dental support), MARPE (Miniscrew-Assisted Rapid Palatal Expansion with skeletal support) [9] and SARPE (Surgically Assisted Rapid Palatal Expansion) [10]. MARPE and SARPE are used in fused MPS or compromised dental support.
The introduction of cone-beam computed tomography (CBCT) in orthodontics allows a quantitative evaluation of BD using Hounsfield units (HU) [11] and an accurate analysis concerning sagittal and vertical growth patterns, which helps to make in the decision of whether to use conventional (RPE) or unconventional maxillary expansion (MARPE or SARPE).
This retrospective study recruited 392 early adolescents aged between 10 and 14 years (196 males, 196 females). For vertical skeletal growth pattern differentiation, the subjects were classified by the Frankfort horizontal line to the mandibular plane angle (hypodivergent < 22°, 22° ≤ normodivergent ≤ 28°, and 28° < hyperdivergent) [12]. In the sagittal growth pattern analysis, the participants were divided by the ANB angle (Class III < 0°, 0° ≤ Class I ≤ 4°, and 4° < Class II) [13] as reported in Table 1.
The BD of the MPS was calculated at 2-time points: preoperatively (T0) one year after the beginning of the treatment with RPE (T1). This study was carried out by using CBCT with a low-dose protocol [14], and the region of interest (ROI) was used to calculate BD in the area between the maxillary incisors (manually standardized in each CBCT scan). The first null hypothesis proposed no difference between males and females in terms of BD in the ROI. The second null hypothesis proposed no difference between different vertical skeletal patterns in terms of BD in the ROI. The third null hypothesis proposed a difference between different sagittal skeletal patterns in terms of BD in the ROI. The fourth null hypothesis proposed no difference between 2-time points (t0 and t1) in BD in the ROI.

# Material and methods

**Study design**
In this retrospective study, CBCT scans of 392 early adolescents aged between 10 and 14 years (196 males, 196 females) treated with RPE appliance were analysed using Dolphin software. The bone density (BD) of the midpalatal suture was calculated at 2-time points: preoperatively (T0) and one year after the beginning of the treatment with RPE (T1).

**Setting (setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection)**
The clinical data were collected from the archives of the Department of Medical, Oral and Biotechnological Sciences of the University "G. D'Annunzio" in Chieti (from 2016 to 2021). Ethical approval (number 23) was obtained by the Independent Ethics Committee of the hospital of Chieti. This study protocol was drawn following the European Union Good Practice Rules and in line with the Helsinki Declaration.

**Participants**
Written informed consent was obtained from all patients included in the study. The clinical data of 392 patients treated with RPE were evaluated in the sample, 196 males and 196 females. Age ranged from 10 to 14 years (early adolescence) [16].
The inclusion criteria were:
- the presence of a transverse maxillary deficiency
- the presence of a unilateral or bilateral posterior crossbite
- the presence of a complete CBCT exam at T0 and T1
- the success of the therapy with RPE appliance

The exclusion criteria were:
- lack of any diagnostic data (including CBCT images at T0 and T1)
- poor-quality CBCT images,
- impacted or missing teeth,
- previous orthodontic treatment,
- dentofacial abnormalities,
- skeletal asymmetry
- any form of syndromes or pathologies involving bone metabolism.

**Treatment**

All patients in the study underwent a transverse maxillary expansion with RPE on dental support: the RPE was initially activated on the chair by performing a complete turn of the screw, which corresponds to 4 activations (1 mm). The patients were instructed to activate the RPE at home, twice a day (0.5 mm expansion a day) until a 2-mm molar transverse overcorrection was achieved (generally for 10 - 15 days). The same RPE was subsequently used as a passive retainer to prevent transverse maxillary relapse for six months, and the screw was locked with a light-cure flow composite. The appliance was removed six months after its last activation, and a second CT scan was performed 12 months after the beginning of the treatment with RPE using the same parameters and condition of the previous exam at T0. Before and after treatment, patients underwent pain assessments (through measures of visual analogue scales and muscular palpation tests). [15]

**CBCT**

All CBCT examinations were taken at T0 and T1 and were performed by the Planmeca Promax® 3D MID unit (Planmeca Oy, Helsinki, Finland) according to the low-dose protocol [14] with these parameters: acquisition time of 15 s, 80 kVp, 5 mA, 35 microSievert (µSv), the field of view (FOV) of 240 × 190.
The patient's CBCT was performed with the head oriented according to the Natural Head Position (NHP); the patient was in a sitting position with the back perpendicular to the floor, as much as possible. The head was stabilised with ear rods in the external auditory meatus. The patient was instructed to look into their own eyes in a mirror, 1.5 m in front of them, to obtain NHP. The NHP is a physiological and reproducible posture defined for the morphological analysis described in the orthodontic and anthropological literature. The 3D image of the cranium was oriented in the Dolphin software according to NHP posture before taking cephalometric measurements. The NHP orientation was carried out by the widgets present in Dolphin; hard and soft tissue views were checked for orientation in the software by visualising the head from the front, right, and left sides. In the NHP, there are three reference planes perpendicular to each other, which are identified on the software for the patient's cephalometric measurements (Figure 1).

- 1. The transverse plane coincides with the Frankfurt plane (FH), a plane passing through two points: Orbital (Or) and Porion (Po);
- 2. The sagittal plane coincides with the mid-sagittal plane (MSP), a plane perpendicular to the plane FH and passing through two points: Crista Galli (Cg) and Basion (Ba);
- 3. The coronal plane coincides with the anteroposterior (PO) plane, perpendicular to the FH and MSP, passing through the right and left Porion.

The same examiner manually defined the ROI and used it to calculate bone density in Hounsfield units (HU). The ROI [17] for all patients is the delimited area (Figure 2):
- superiorly by the upper central incisors' apex,
- laterally by the upper central incisors' medial root surface,
- inferiorly by the cementoenamel unction
- posteriorly by the anterior edge of the nasopalatine foramen.

Sex gender, vertical and sagittal skeletal patterns were used to categorize the sample into 8 groups:
Sex gender
- Males (n 196, 50% of 392 patients)
- Females (n 196, 50% of 392 patients)

Vertical skeletal pattern
- Hypodivergent (n 122, 31,1% of 392 patients)
- Normovergent (n 141, 36,0 % of 392 patients)

- Hyperdivergent (n 129, 32,9% of 392 patients)

Sagittal skeletal pattern

- Class I (n 139, 35,5% of 392 patients)
- Class II (n 106, 27,0% of 392 patients)
- Class III (n 147, 37,5% of 392 patients)

Each measurement was performed by the same examiner on the first (T0) and second (T1) CBCT scan for all the patients, as reported in Table 1.

**Error method**

All the CBCT images were randomly selected and analysed to evaluate the reliability of this study. In order to validate the repeatability and reproducibility of a quantitative evaluation of BD and assess intraoperator and interoperator errors, the CBCT data of the patients were processed by the same operator twice; the Wilcoxon signed-rank test evaluated changes in the calculated BD between the first and the second measurements. No significant difference was observed between the two measurements for the BD.

**Statistical Analysis**

Simple descriptive statistics were used to summarise the data, as reported in Table 1. Mean and standard deviation (σ) were computed for BD at T0 and T1 for each category of patients: males, females, hypodivergent, normodivergent, hyperdivergent, class I, class II and class III. The one-sample Kolmogorov–Smirnov test was used to test the normality of BD for the various categories (gender, vertical and sagittal skeletal patterns) [reference: A CBCT Evaluation of Midpalatal Bone Density in Various Skeletal Patterns]. The values of the K-S test statistic are 0.19 ($p = 0.88$) at T0 and 0.24 ($p = 6.73$) at T1, so the assumption of normality is not violated because the data do not differ significantly from what is usually distributed. The values of density at the same time point (means, standard deviation and n) were analysed by independent sample t-test in terms of sex gender (male and female), vertical skeletal pattern (hypodivergent vs hyperdivergent, hypodivergent vs normodivergent, normodivergent vs hyperdivergent) sagittal skeletal pattern (I class vs II class, I class vs III class, II class vs III class). Statistical analyses were performed using GraphPad Prism software (GraphPad Software Inc., San Diego, CA, USA). Friedman repeated-measures ANOVA computed the changes in density from T0 to T1 on ranks followed by the Tukey post-hoc test. The level of significance was set at $P < 0.05$.

**Results**

CBCT scan data for 392 patients (196 females and 196 males) who had a mean age of 11,7 years (range from 10 to 13.9 years) and underwent RPE were included in the study. The bone densities in HU for different categories (sex, gender and skeletal pattern) and for different time points (t0 and t1) are shown in Table 1.

**Sex comparison**

- At t0, the two-tailed P-value is less than 0.0001. By conventional criteria, this difference is extremely statistically significant ($p > 0.05$). The mean of females minus males equals 12.8900 (95% confidence interval, $t = 4.6770$, $df = 390$, standard error of difference = 2.756).
- At t1, the two-tailed P-value is less than 0.0003. By conventional criteria, this difference is extremely statistically significant ($p > 0.05$). The mean of females minus males equals 9.3300 (95% confidence interval, $t = 3.6400$, $df = 390$, standard error of difference = 2.563). The means bone density (547.59 ± 28.60 HU at t0, 542.31 ± 23.03 HU at t1) in the group of males (196 subjects) were significantly lower than that (560.17 ± 25,90 HU at t0, 551,64 ± 27.52 HU at t1) in the group of females (196 subjects).

**Hypodivergent vs normodivergent**

- At t0, the two-tailed P value equals 0.1992. By conventional criteria, this difference is not statistically significant ($p < 0.05$). The mean of hypodivergent minus normodivergent equals 4.0200 (95% confidence interval, $t = 1.2872$, $df = 261$, standard error of difference = 3.123).
- At t1, the two-tailed P value equals 0.4972. By conventional criteria, this difference is considered to be not statistically significant ($p < 0.05$). The mean of hypodivergent minus normodivergent equals 2.0700 (95% confidence interval, $t = 0.6799$, $df = 261$, standard error of difference = 3.044) The means bone density

(552.17 ± 27.26 HU at t0, 544.46 ± 24.45 HU at t1) in the group of hypodivergent (122 subjects) were slightly higher than that (548.15 ± 23,39 HU at t0, 542,39 ± 24.77 HU at t1) in the group of normodivergent (141 subjects), but not statistically significant.

**Hyperdivergent vs normodivergent**
- At t0, the two-tailed P value equals 0.4476. By conventional criteria, this difference is considered to be not statistically significant. The mean of hyperdivergent minus normodivergent equals 2.2800 (95% confidence interval, t = 0.7605, df = 268, standard error of difference = 2.998).
- At t1, the two-tailed P value equals 0.7650. By conventional criteria, this difference is considered to be not statistically significant. The mean of hyperdivergent minus normodivergent equals 0.8600 (95% confidence interval, t = 0.2992, df = 268, standard error of difference = 2.874) The means bone density (550.43 ± 25.87 HU at t0, 543.25 ± 22.25 HU at t1) in the group of hyperdivergent (129 subjects) were slightly higher than that (548.15 ± 23,39 HU at t0, 542,39 ± 24.77 HU at t1) in the group of normodivergent (141 subjects), but not statistically significant.

**Hypodivergent vs hyperdivergent**
- At t0, the two-tailed P value equals 0.6043. By conventional criteria, this difference is considered to be not statistically significant. The mean of hyperdivergent minus hypodivergent equals -1.7400 (95% confidence interval, t = 0.5189, df = 249, standard error of difference = 3.354).
- At t1, the two-tailed P value equals 0.6838. By conventional criteria, this difference is not statistically significant ($p < 0.05$). The mean of hyperdivergent minus hypodivergent equals 1.2100 (95% confidence interval, t = 0.4077, df = 249, standard error of difference = 2.968). The means bone density (550.43 ± 25.87 HU at t0, 543.25 ± 22.23 HU at t1) in the group of hyperdivergent (129 subjects) were slightly lower than that (552.17 ± 27.26 HU at t0, 544.46 ± 24.77 HU at t1)) in the group of hypodivergent (122 subjects), but not statistically significant.

**I class vs II class**
- At t0, the two-tailed P value equals 0.2338. By conventional criteria, this difference is not statistically significant ($p < 0.05$). The mean of I class minus II class equals 3.8600 (95% confidence interval, t = 1.1936, df = 243, standard error of difference = 3.234).
- At t1, the two-tailed P value equals 0.7414. By conventional criteria, this difference is not statistically significant ($p < 0.05$). The mean of I class minus II class equals 1.0900 (95% confidence interval, t = 0.3304, df = 243, standard error of difference = 3.299). The means bone density (560.78 ± 25.54 HU at t0, 551.12 ± 23.27 HU at t1) in the group of I class (139 subjects) were slightly higher than that (556.92 ± 24.46 HU at t0, 550.03 ± 28.34 HU at t1) in the group of II class (106 subjects), but not statistically significant.

**I class vs III class**
- At t0, the two-tailed P value equals 0.1056. By conventional criteria, this difference is not statistically significant ($p < 0.05$). The mean of III class minus I class equals 5.0700 (95% confidence interval, t = 1.6235, df = 284, standard error of difference = 3.123).
- At t1, the two-tailed P value equals 0.2783. By conventional criteria, this difference is not statistically significant ($p < 0.05$). The mean of III class minus I class equals 3.0800 (95% confidence interval, t = 1.0862, df = 284, standard error of difference = 2.836). The means bone density (560.78 ± 25.54 HU at t0, 551.12 ± 23.27 HU at t1) in the group of I class (139 subjects) were slightly higher than that (565.85 ± 27.18 HU at t0, 554.20 ± 24.61 HU at t1) in the group of III class (147 subjects), but not statistically significant.

**II class vs III class**
- At t0, the two-tailed P-value is less than 0.0077. By conventional criteria, this difference is considered very statistically significant ($p > 0.05$). The mean of III class minus II class equals 8.9300 (95% confidence interval, t = 2.6875, df = 251, standard error of difference = 3.323).
- At t1, the two-tailed P value equals 0.2134. By conventional criteria, this difference is not statistically significant ($p < 0.05$). The mean of III class minus II class equals 4.1700 (95% confidence interval, t = 1.2474, df = 251, standard error of difference = 3.343). The means bone density (565.85 ± 27.18 HU at t0, 554.20 ±

24.61 HU at t1) in the group of III class (147 subjects) were significantly higher than that (556.92 ± 24.46 HU at t0, 550.03 ± 28.34 HU at t1) in the group of II class (106 subjects).

**T0 vs T1**

- No statistically significant differences were found between the 2-time points (from T0 to T1) in any groups ($p < 0.05$).

# Discussion

The purpose of this paper was to evaluate the RPE effects in terms of BD of the MPS in growing patients (10-14 years). A low-dose CBCT protocol was used for better identification of landmarks and to reduce the radiation exposure of the patients. The ROI in the MPS showed a lack of statistically significant differences from T0 (preoperatively) to T1 (one year after the beginning of the therapy), according to Lione et al. (Three-dimensional densitometric analysis of maxillary sutural changes induced by rapid maxillary expansion), who found similar results between T0 (preoperatively) and six months after the beginning of RPE, in addition, they found a significant reduction in density between T0 and the end of the active expansion phase (14 days after T0), due to the orthopaedic forces of RPE that determined lateral displacement of the two hemi-maxillae. This result was confirmed by Fastuca et al. [18]. The RPE is kept in place as a passive retainer to avoid the transverse maxillary relapse and maintains the two halves of the maxilla separately while the mineralization of the MPS increases. The failure of maxillary expansion is not an unusual occurrence in adolescent and young adult patients in terms of lack of increase in transverse width and terms of adverse effects such as periodontal attachment loss, increased mobility, uncontrolled tipping, root reabsorption, necrosis, vestibular fenestration [19]. MPS fusion classification using CBCT provides reliable parameters for the clinical decision between conventional (RPE) and unconventional (MARPE, SARPE). According to Angelieri et al. [8], there are five stages of MPS maturation. Stages A (straight high-density sutural line, with no or little interdigitation) and B (scalloped appearance of the high-density sutural line) frequently were noted up at 13 years of age; stage C (parallel, scalloped, high-density lines that were close to each other, separated in some areas by small low-density spaces) was observed typically from 11 to 17 years (rarely in younger and older patients). Patients in stages D (fusion completed in the palatine bone, with no evidence of a suture) and E (fusion anteriorly in the maxilla) might be better treated by SARPE because fusion of the MPS already has occurred. Females showed significantly higher BD of the MPS than males, and the first null hypothesis was rejected. No difference between different vertical skeletal patterns (hypodivergent vs normodivergent, hyperdivergent vs normodivergent, hypodivergents vs hyperdivergent) and between BD values before (t0) and after RPE (t1) was found, and the second and fourth null hypotheses were not rejected. Similar results were found in the literature by Chae [16]; Class III skeletal individuals showed a significantly higher BD value than the II class group at T0, but not at T1. No difference between other sagittal skeletal patterns groups was found, so the third null hypothesis was partially rejected. These results were confirmed in the literature. The MPS suture showed homogeneous density values before treatment (T0) in each category (547.59 HU, 560.48 HU, 552.17 HU, 548.15 HU, 550.43 HU, 565.85 HU, 560.78 HU, 556.92 HU). RPE performed the maxillary expansion, and the opening of the MPS was achieved with success in all patients. In literature, it is reported that it was possible to open sutures with RPE when BD values of the MPS ranged from 563.3 to 741.7 HU, as confirmed by Lione et al.[20] The MPS suture also showed homogeneous density values after treatment (T1) in each group (542.31 HU, 551.64 HU, 544.46 HU, 542.39 HU, 543.25 HU, 554.20 HU, 551.12 HU, 550,03 HU), and the density values of MPS at t1 were similar to T0, suggesting that a similar rate of suture reorganization occurs one year after the use of the RPE, following reorganization and bone deposition along with the MPS.

# Conclusion

The first null hypothesis should be rejected, and it can be concluded that the female group showed a significant higher BD value than the males' group at t0 (preoperatively) and t1 (post-operatively). The second null hypothesis should not be rejected because there was no difference between different vertical skeletal patterns in BD values of MPS at t0 and t1. The third null hypothesis should be partially rejected because only the III class group showed a significant higher BD value than the II class group at T0, but not at T1 and in

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addition, there is no difference between other sagittal skeletal patterns groups in terms of BD values of MPS at t0 and t1. The fourth null hypothesis should not be rejected because there was no difference between BD values before and after RPE.

## Author Contributions

F.F. and M.M. documented the cases. M.M., E.T. and G.V. conducted a review of literature. M.M. and G.M. drafted the manuscript. M.M and G.V. analysed the data. All authors contributed to the article and approved the submitted version of the manuscript.

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## Institutional Review Board Statement

The study involving human participants were reviewed and approved by ethics approval (number 23) was obtained by the Hospital's Independent Ethics Committee of Chieti.

## Informed Consent Statement

Informed consent was obtained from all subjects involved in this study.

## Conflicts of Interest

The authors declare no conflict of interest.

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**Table 1. Midpalatal bone density (BD) according to sex gender and skeletal pattern (HU).**

| Mean (µ) and Standard Deviation (σ) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Sex gender | | Vertical skeletal pattern | | | Sagittal skeletal pattern | | |
| | | Males | Females | Hypo-divergent | Normo-divergent | Hyper-divergent | Class-III | Class-I | Class-II |
| n | | **196** | **196** | **122** | **141** | **129** | **147** | **139** | **106** |
| **T0** | µ (Hu) | 547.59 | 560.48 | 552.17 | 548.15 | 550.43 | 565.85 | 560.78 | 556.92 |
| | σ | 28.60 | 25.90 | 27.26 | 23.39 | 25.87 | 27.18 | 25.54 | 24.46 |
| **T1** | µ (Hu) | 542.31 | 551.64 | 544.46 | 542.39 | 543.25 | 554.20 | 551.12 | 550,03 |
| | σ | 23.03 | 27.52 | 24.45 | 24.77 | 22.23 | 24.61 | 23.27 | 28.34 |

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**Figure 1**

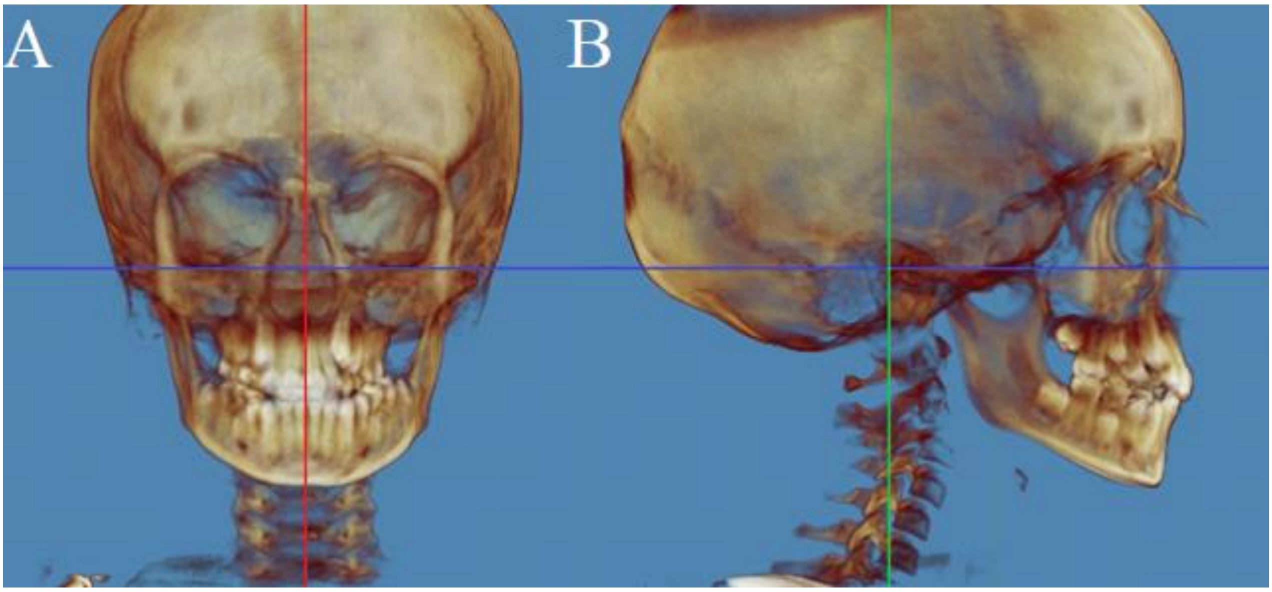


Fig. 1 Spatial orientation of the CBCT scans according to the Natural Head Position (NHP). The T0 and T1 scans are from the same patient. (A) The red line in the coronal orientation coincides with the mid-sagittal plane (MSP), a plane perpendicular to the plane FH and passing through Crista galli (Cg) and Basion (Ba) points. (B) The blue line in the sagittal orientation coincides with the Frankfurt plane (FH), a plane passing through Orbital (Or) and Porion (Po) points; the green line coincides with the anteroposterior (PO) plane, perpendicular to the FH and MSP, passing through the Porion.

**Figure 2**

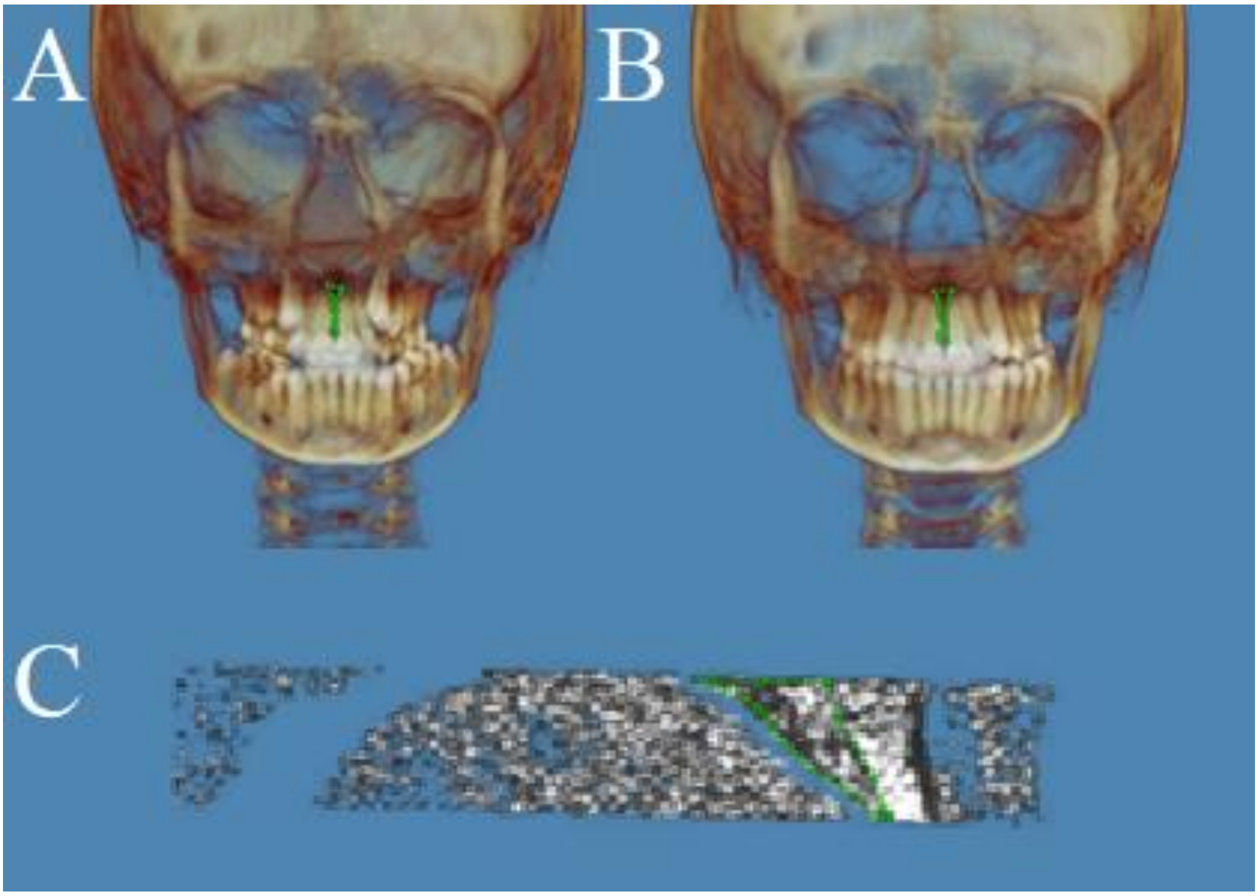

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Fig. 2 The region of interest (ROI) was selected at T0 (A) and at T1 (B) as shown in green. The ROI is delimited superiorly by the upper central incisors' apex, laterally by the upper central incisors' medial root surface, inferiorly by the cementoenamel unction (A e B). The ROI is delimited posteriorly by the anterior edge of the nasopalatine foramen (C).