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DEVELOPMENTAL STUDY

Contemporary skull development – palatal angle analysis

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Abstract: *Objectives:*The palatal angle is an important angle of the craniofacial complex. It is significant for the diagnosis of craniofacial disorders mainly for nasopharyngeal soft-tissue patterns.
Background The dentists and otorhinolaryngologists use this relationship to establish proper treatment mechanics and evaluate facial profile. The aims of this study were to provide comparative cephalometric analyses of historical and contemporary skulls.
*Materials and method:*A total of 190 cephalograms of 2 groups of subjects were evaluated. Dolphin Imaging 11.0 – Cephalometric Tracing Analysis was used for the analysis. Unpaired two-tailed t-test assuming equality of variances was used for all variables (at the significance level p = 0.0001).
Results: The modern forensic skulls had larger palatal angle at average value of 8.60 degrees ± 4.35, than that of archeological ones, the average value of which was 6.50 degrees ± 3.92. The difference was found significant. Unpaired two-tailed t-test assuming equality of variances showed that historical and contemporary skulls had statistically significant results. The difference was –2.09 with standard error of 0.60 (95% confidence interval from –3.29 to –0.89). Two-tailed probability attained value of P was less than 0.0001.
Conclusion: The difference between both groups was found significant. An increase in the palatal angle can be directly connected with anterior rotation of upper jaw*(Tab. 2, Fig. 5, Ref. 19).*Text in PDF *www.elis.sk.*
Key words: dentistry, otorhinolaryngology, craniofacial complex, cephalometric radiograph, palatal angle analysis.

Introduction

The maxilla develops postnatally entirely by intramembranous ossification. Since there is no cartilage replacement, the growth occurs in two ways, namely by apposition of bone at the sutures that connect the maxilla to the cranium and cranial base, and by surface remodeling. Maxilla grows downward and forward, which is allowed by the ideally situated sutures attaching the maxilla posteriorly and superiorly and by growth of the cranial base behind it. The growth pattern of the maxilla has been described by Björk in 1955 (1). He used metallic implants in the right side of each arch to analyze growth mechanism of individual human bones on the basis of comparison with the external bone contours. The growth in length is sutural towards the palatine bone. The space at the sutures is filled in by proliferation of bone. The sutures retain the same width, and various processes of the maxilla become longer. This is accompanied by periostal apposition at the maxillary tuberosity, as a free surface. Bone addition creates additional space into which the primary and then the permanent molar teeth successively erupt. The growth in length has not been found on the anterior surface of the maxilla, apart from the alveolar process, as almost the entire anterior surface of the maxilla is an area of resorption, not apposition.

The growth in height takes place at the sutural articulations of the frontal and zygomatic processes, and by periostal apposition on the lower border of the alveolar process. The nasal floor is lowered through resorption together with periostal apposition on the hard palate, and the anterior nasal spine is likewise lowered through resorptive remodeling. The overall growth changes result from both downward and forward translation of the maxilla and simultaneous surface remodeling. The whole bony nasomaxillary complex is moving downward and forward relative to the cranium, being translated in space (2–6).

The knowledge of growth changes and possibility of their influence have fundamental significance for the treatment of orthodontic anomalies. As a research tool, cephalometry has been the most widely used imaging modality in orthodontic investigations. Cephalometry has been used to quantify craniofacial parameters in individuals or sample population, distinguish normal from abnormal anatomy, compare treated and untreated sample populations, differentiate homogeneous from mixed populations, and to assess patterns of change through time.

Palatal angle is one of values which serve to determine whether upper jaw rotates more intensively forward and down or vice versa. To determine this angle we use upper palatal plane which is a connection of two points, namely anterior nasal spine (ANS) and posterior nasal spine (PNS) as well as anterior cranial base which is also a connection of two points, namely Sella (S) and Nasion

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Tab. 1.Palatal angle – current orthodontic analysis.

SN- Palatal plane			
Analysis	Mean	SD	Reference
Bell, Proffit and White	7	± 3	*Athanasios E. Athanasiou: Orthodontic cephalometry. Mosby-Wolfe, 1995.*
Bjork-Cranio-Mx Base/SN-Palatal Plane (º)	7.3	3.5	*Dolphin user guide manual 6.0, Dolphin Computer Access www.DolphinGuide.com (2012).*
SN-PP Class I male female	8.97 9.38 8.57	± 3.05 ± 3.43 ± 2.57	*Hiroshi Iwasaki, Hiroyuki Ishikawa, Lamiya Chowdhury, Shinji Nakamura, and Junichiro Iida. Properties of the ANB angle and the Wits appraisal in the skeletal estimation of Angle's Class III patients Eur J Orthod 2002; 24(5): 477–483.*
SN-PP Class III male female	9.91 10.29 9.67	± 3.01 ± 3.06 ± 2.96	*Hiroshi Iwasaki, Hiroyuki Ishikawa, Lamiya Chowdhury, Shinji Nakamura, and Junichiro Iida. Properties of the ANB angle and the Wits appraisal in the skeletal estimation of Angle's Class III patients Eur J Orthod2002; 24(5): 477–483.*
Vertical Cephalometric Analysis	8	± 2	*Alió-Sanz JJ. A new cephalometric diagnostic method for Down's Syndrome patients with open bite. Med Oral Patol Oral Cir Bucal 2008;13(3):E171–175.*
(Vertical cephalometric analysis is a calibrated method specifically for the differential diagnosis of skeletal and dentoalveolar open bites.)			
SN-PP (°) control group treated group	 8.62 9.95	 2.98 3.76	*Cozza P, Giancotti A, Petrosino A. Rapid palatal expansion in mixed dentition using a modified expander: a cephalometric investigation. J Orthod 2001;28(2):129–134.*
SN-PP before treatment after treatment	 6.88 6.79	 2.72 2.80	*PINTO, Francisco Marcelo Paranhos et al. Vertical growth control during maxillary expansion using a bonded Hyrax appliance. Dental Press J Orthod [online]. 2012, vol.17, n.1 [cited 2013-02-25], pp. 101–107.*
SN-PP Class I Class II Class III Open bite	 6.8 5.8 7.5 6	 3.7 3.2 7.3 5.2	*Celar AG, Freudenthaler JW, Celar RW, Jonke E, Schneider B. The denture frame analysis: an additional diagnostic tool Eur J Orthod1998; 20(5): 579–587.*

(No statistical difference was found between the groups i the angle SN-PP.)

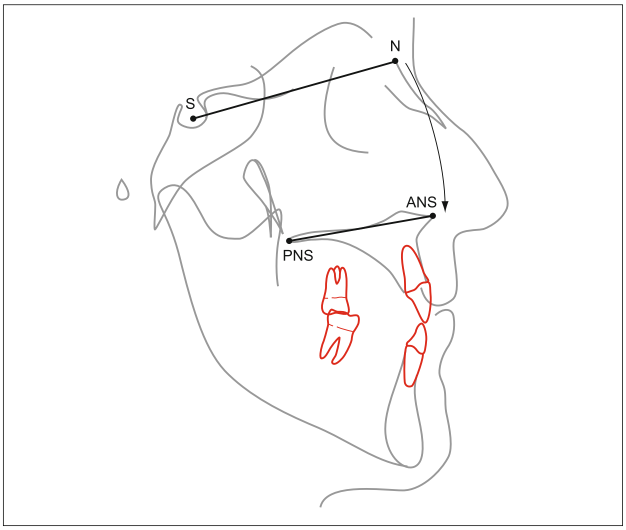

Fig. 1.Anterior cranial base (N-S line); palatal plane (ANS-PNS line).

(N) on cephalometry (Tab. 1, Fig. 1). The normal value of palatal angle for European population is about 8.1° (7). Deviation grows significantly forward and down and the angle shows the degrees of declination of the maxilla to the cranial base.

The importance of correct identification of the anteroposterior jaw relationship is essential. The clinician uses this relationship to establish detailed treatment goals and proper treatment mechanics. It has often been observed that the intermolar relationship is not necessarily related to the facial profile. When analyzing cephalometrics, many patients with Class I molar relationship show an obvious Class II or Class III pattern in their facial profile. Most of these cases show abnormal rotation of the jaws relative to cranial anatomy (8–11).

The horizontal relationship of denture bases can be defined using the angles or distances between reference planes of the craniofacial complex and points A and B, which are representative of the anterior limits of denture bases. The skeletal A-P relationship is probably affected by the vertical jaw relationship. In other words, the degree of A-P relationship can vary in response to a vertical change in facial dimension (5). Accordingly, it might be said that the skeletal sagital aspect could be described more adequately by angles between craniofacial reference planes and A-B plane, which is supplemented by a consideration of both vertical and horizontal distances between points A and B, concurrently.

Therefore, the aims of this study were 1) to examine statistically and geometrically the different cephalometric measurements which are used to indicate SN – palatal planerelationship, and 2) to providecomparative cephalometric analysis of historical and contemporary forensic skulls.

Material and methods

Palatal angle size and relationship of the angle size in modern (forensic) and archeological skulls were investigated in this study. A total of 190 cephalograms of 2 groups of subjects, namely forensic (75 unknown individuals; 67 men and 8 women from Institute of Criminalistics, Prague, Czech Republic) and archeological subjects (115 skulls dated 8th–12th century; excavations of Slavic settlements in Czech and Moravian regions), were evaluated. The lateral cephalograms were taken under standard conditions. The sensor–focus distance from the median plane of the patient's head

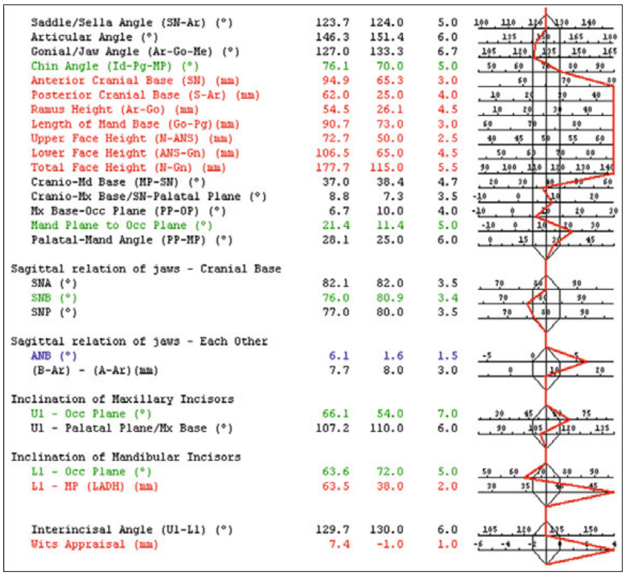

Fig. 2. Dolphin Imaging 11.0 – current forensic skull cephalometric analysis.

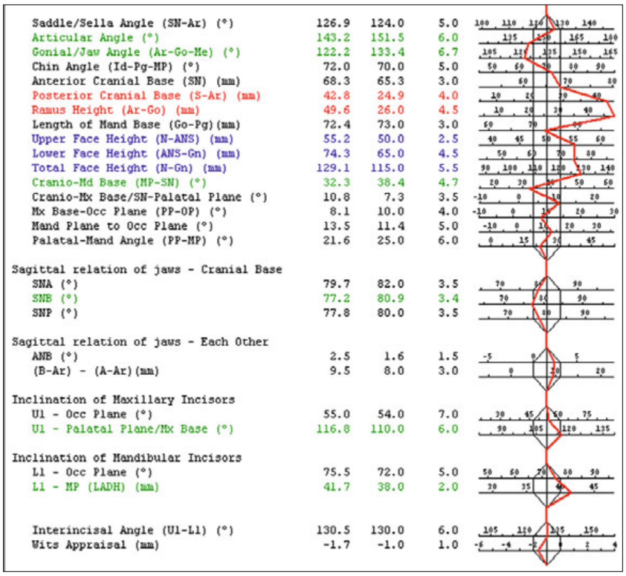

Fig. 3. Dolphin Imaging 11.0 – archeological skull cephalometric analysis.

was 150 cm, and the median plane–sensor distance was 10 cm. The cephalograms of contemporary group were taken with the subjects standing with the head positioned in the cephalostat and orientated to the Frankfort horizontal plane parallel to the underlay. To minimize error, all measurements were made by the same person.

Dolphin Imaging 11.0 – Cephalometric Tracing Analysis (CephX Inc. Las Vegas, NV) was used for the analysis (Figs 2 and 3).

All subjects were of Caucasian origin and therefore ethnically represented a very homogeneous group. All cephalometric radiographs of these subjects were made with the same panoramic machine (Gendex, Oralix 9200, Milan, Italy). Cephalometric Tracing Analysis was performed by two orthodontists (Fig. 4).

Statistical evaluation

The subjects were divided into 2 groups (75 contemporary forensic skulls, 115 archeological samples) to compare the palatal angle differences. Unpaired two-tailed t-test assuming equality of variances was used for all variables (at the significance level p = 0.0001).

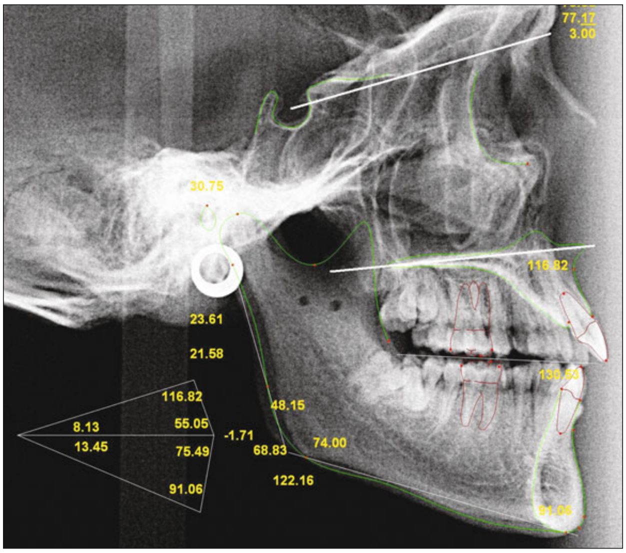

Fig. 4. Dolphin Imaging 11.0 – Cephalometric Tracing Analysis – palatal angle.

Results

The modern forensic skulls had larger average palatal angle value, namely 8.60 degrees ± 4.35, than the archeological ones, the average value of which was 6.50 degrees ± 3.92. The difference was found significant. Unpaired two-tailed t-test assuming equality of variances showed that forensic and archeological skulls had statistically significant results. The difference was -2.09 with standard error of 0.60 (95 % confidence interval from –3.29 to –0.89). Two-tailed probability attained the value of P less than 0.0001 (Tab. 2).

The significant difference existed in measurements of the palatal angle between forensic and archeological dentate groups. We were able to confirm discrepancies in shape of maxilla including box plot in interval (Fig. 5).

A comparison of the mean data for the two groups indicates that the mean palatal angle for the forensic skulls was 8.60 degrees (with a variance of 18.96) in comparison to the archeological skulls whose mean palatal angle was 6.50 degrees (with a lower variance of 15.36).

Tab. 2.Palatal angle evaluation.

	Palatal angle	
	Modern (forensic) sculls	Archeological sculls
N	75	115
Mean	8.6	6.5
95% Cl	7.6 to 9.6	5.8 to 7.2
SD	4.4	3.9
F-test	p = 0.31	
T test (two tailed probability)	p = 0.0007	

Fig. 5.Palatal angle analysis – statistical evaluation.

As the P value for the analysis was less than 0.0001, we can conclude that the hypothesis of different palatal angle is statistically significant. From the measurements, we have shown that the type of life style had direct influence on anatomy of skull in the palatal angle area.

When the results were compared with contemporary orthodontic cephalometric analysis (Tab. 1) it was evident that all mentioned groups excluding children (12, 13) had also higher palatal angle, namely from 7.00 to 10.29 degrees.

Discussion

The palatal angle is an important angle of the craniofacial complex. It is significant for the diagnosis of craniofacial disorders mainly for nasopharyngeal soft-tissue patterns. Nasal fossa, cranial base, and adenoidal tissue were larger in men. All variables except lower pharynx dimension were statistically related. Great dependence was observed between some variables, namely the upper airway thickness explained 60% of the changes in upper pharyngeal dimension and 67% of changes in aerial area. Cranial base length was related to different variables defining the airway, mainly nasal fossa length and lower airway thickness. Palatal angle was statistically correlated with upper airway area (14) and this space has direct influence on obstructive sleep apnea (15). Also cleft patient ANB angle was the most significant predictor for later osteotomy. Despite individual variation, all children (n = 13) whose ANB angle was less than 7°, needed later orthognathic surgery; whereas, none of those whose ANB angle was greater than 12.5° (n = 6) needed maxillary osteotomies (16).

Lateral cephalogram or three-dimensional cone beam computed tomography can be usually used to determine this angle (17). Smith (18) found that computerized cephalometric analysis yields comparable results to traditional cephalometric analysis, but can be used also for skulls.Cephalometric tracing analysis helped us capture standardized images and achieve precise measurement.

Genetic drift is rejected as a predominant mechanism influencing the maxilla shape in *Homo sapiens* (19). Our results confirmed that palatal angle size is also connected with assessing the morphology of the maxilla and had direct influence on upper jaw development. We found a significant difference between the archeological and forensic groups. An increase in the palatal angle can be directly connected with less marked anterior rotation of upper jaw. Also this result was statistically significant.

The considerable transformative changes in the palatal angle may be attributed to several factors, and it is known that the maxilla does not follow one characteristic pattern throughout the development. The present study concludes that during the development, there seems to be a significant difference in the palatal angle. At present, the palatal angle shows to be definitely increased.

References

1. **Björk A.** Facial growth in man, studied with the aid of metallic implants. ActaOdontolScand 1955; 13 (1): 9–34.

2. **Björk A.** Sutural Growth of the Upper Face Studied by the Implant Method. ActaOdontolScand 1966; 24 (2): 109–127.

3. **Björk A, Skieller V.** Growth of the maxilla in three dimensions as revealed radiographically by the implant method. Br J Orthod 1977; 4 (2): 53–64.

4. **Ochoa BK, Nanda RS.** Comparison of maxillary and mandibular growth. Am JOrthodDentofacOrthop. 2004; 125 (2): 148–159.

5. **Proffit WR, Fields H W, Sarver DM.** Contemporary Orthodontics. St. Louis, Mo: Mosby Elsevier. 2007.

6. **Yang SD, Suhr CHH.** F-H to AB plane (FABA) for assessment of anteriorposterior jaw relationship. Angle Orthod 1995; 65 (3): 223–232.

7. **Hasund A, Stenger D.** Individualizovanákefalometrie, Prague,1994.

8. **Alió-Sanz JJ.** A new cephalometric diagnostic method for Down's syndrome patients with open bite. Med Oral Patol Oral Cir Bucal 2008:13 (3);E171–175.

9. **Cozza P, Giancotti A, Petrosino A.** Rapid palatal expansion in mixed dentition using a modified expander: a cephalometric investigation. J Orthod 2001; 28 (2): 129–134.

10. **Dolphin guide user manual 6.0,** Dolphin Computer Accesswww.DolphinGuide.com.2012

11. **Iwasaki H, Ishikawa HI, Chowdhury L, Nakamura S, Iida J.** Properties of the ANB angle and the Wits appraisal in the skeletal estimation of Angle's Class III patients.Eur J Orthod 2002; 24 (5): 477–483.

12. **Celar AG, Freudenthaler JW, Celar RM, Jonke E, and Schneider B.** The denture frame analysis: an additional diagnostic tool. Eur J Orthod 1998; 20 (5): 579–587.

13. **Pinto FMP.** Vertical growth control during maxillary expansion using a bonded Hyrax appliance. Dental Press J Orthod 2012; 17 (1): 101–107.

14. **Martin O, Muelas L, Viñas MJ**. Nasopharyngeal cephalometric study of ideal occlusions.Am J OrthodDentofacialOrthop 2006; 130 (4): 436e1–9.

15. **Heliövaara A, Leikola J, Hukki J.**Craniofacial cephalometric morphology and later need for orthognathic surgery in 6-year-old children with bilateral cleft lip and palate. Cleft Palate Craniofac J 2013; 50 (2): e35–40.

16. **Guijarro-Martínez R, Swennen GR.** Three-dimensional cone beam computed tomography definition of the anatomical subregions of the upper airway: a validation study. Int J Oral MaxillofacSurg 2013Apr 25. pii: S0901-5027(13)00117-3. doi: 10.1016/j.ijom.2013.03.007. [Epub ahead of print]

17. **Erkan M, Gurel HG, NurM .**Reliability of four different computerized cephalometric analysis programs. Eur J Orthod 2012; 34 (3): 318–321.

18. **Smith HF**. The role of genetic drift in shaping modern human cranial evolution: a test using microevolutionary modeling. Int J EvolBiol 2011; 145–262.

19. **Ping-Ying Chiang R, Lin CM, Powell N, Chiang YC, Tsai YJ**.Systematic analysis of cephalometry in obstructive sleep apnea in Asian children. Laryngoscope2012; 122 (8): 1867–1872.

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CLINICAL STUDY

Proclination-induced changes in the labial cortical bone thickness of lower incisors

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ABSTRACT

OBJECTIVES: We sought to objectivize the overall alveolar bone thickness changes in lower incisors after orthodontic intervention.

BACKGROUND: The effect of orthodontic treatment on the cortical bone, specifically the clinical implications of proclination-induced change, have long been a matter of dispute.

METHODS: Cone-beam computed tomographs of 58 patients were obtained before and after treatment and labial cortical bone thickness and overall alveolus width were measured in sagittal sections in the distance of 3, 6, 9 and 12 mm apically from the cemento-enamel junction.

RESULTS: A statistically significant decrease of the cortical bone thickness in all four incisors was found at the levels 3, 6 and 9 mm ($p < 0.05$), with mean differences of 0.19, 0.10 and 0.14 mm, respectively. The cortical bone thickness at the level of 12 mm and alveolar width at all the levels showed no significant changes ($p > 0.05$). Moreover, no correlation was found between bone thickness change and extent of the incisor movement.

CONCLUSION: Our results point to a marked cortical bone loss after proclination of lower incisors, furnishing a sound basis for caution in treatment planning due to the considerable risk of alveolar defect development, especially in patients with low initial bone thickness *(Tab. 6, Fig. 2, Ref. 25).* Text in PDF *www.elis.sk.*

KEY WORDS: orthodontics, cone-beam computed tomography, incisor, cortical bone, bone remodeling.

Abbreviations: CBCT – cone-bean computed tomography, SD – standard deviation, T1 – before treatment, T2 – after treatment, IMPA – Incisor mandibular plane angle, L1-APo – position of the lower incisor relative to A-Pogonion line, CEJ – Cementum-enamel junction

Introduction

The position of the lower incisors is of paramount importance in the orthodontic diagnosis and treatment. To understand the failures and potential perils associated with the interference in this area, it is necessary to consider the precise mechanical and biological mechanisms that underlie their artificial movement. In turn, this requires understanding of the processes in terms of their multifactorial limitations imposed by the periodontal status in the area (1), the morphology of the symphysis (2, 3) as well as the dimensions of the anterior alveolus (2). These factors must be considered in the treatment plan, balancing the speed and the extent of movement to achieve a stable final position on one side and the notable risk of iatrogenic damage on the other (2, 4).

As yet, several studies have analyzed periodontal status after the treatment, reporting the risk of gingival retraction, external root resorption, dehiscences and fenestrations (1, 4–7). In their influential paper on this topic, MULIE AND HOEVE (4) were the first to draw the attention of the clinical community to the inhibition of the orthodontic movement, dehiscences and fenestrations associated with the contact of the root and the cortical plate. Nonetheless, alveolar defects are consistently observed in treatment-naive individuals (8–11). Ergo, this initially reduced bone support, especially in the case of a narrow and high symphysis (12), markedly increases the potential risk of progressive bone loss if combined with heavy forces and short-term orthodontic activation not allowing complete adaptation of the bone (13). At the same time, the majority of authors agrees on the incidence of these alveolar defects being at a clinically acceptable level and do not consider orthodontic intervention contraindicated even in patients with potential risks (2, 14).

In this study, we addressed the question stated above by means of cone-bean computed tomography (CBCT), which proved to be an accurate imaging tool in investigations of this nature (10), and evaluated the labial cortical bone thickness and the overall alveolar bone thickness in lower incisors before and after orthodontic

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treatment. Our premise was that their proclination should induce a drop in the cortical bone thickness at the levels more distant from the tooth apex and, at the same time, leave the deep areas around the apex itself unchanged.

Material and methods

A total of 58 patients (39 women, average age 23.2 years, SD 6.5) from a private orthodontic practice were enrolled in this retrospective cross-sectional study. Complete treatment records of all the subjects, including pretreatment and posttreatment measurements and CBCT scans, were collected. Only patients with Angle class I or class II malocclusion, with mild to moderate crowding were selected. All patients had complete dental arches (besides third molars) without active eruption of teeth. The following exclusion criteria were implemented: any medical concerns of non-orthodontic nature, class III malocclusion, periodontal diseases (gingival inflammation and bone resorptions), severe crowding in the lower dental arch, missing teeth, history of previous orthodontic treatment and trauma, prosthetic restoration, endodontic, periodontal pathologies and surgeries in the evaluated region. All the subjects completed orthodontic treatment lead by one orthodontist with fixed appliance, without extractions, where crowding was alleviated by the proclination of the lower incisors. Straight-wire mechanics and brackets with Roth prescription, with the .022” slot, were used. All patients signed informed consent with the retrospective analysis of their anonymized data and the study was approved by the Ethical Committee of Charles University, 2nd Faculty of Medicine and the Motol University Hospital (IRB approval No. EK-973IGA 1.12/11).

Cephalometric analysis

Cephalometric analysis was performed at both time points using Dolphin Imaging Software (Dolphin Imaging, Chatsworth, CA, US). Quantitative assessment (angular and linear measurements) of the incisor movement was performed. The axial inclination of lower incisors was measured as the incisor mandibular plane angle (IMPA) in degrees. Mandibular incisor protrusion in millimeters was measured as the position of the lower incisor relative to A-Pogonion line (L1-APo).

CBCT analysis

CBCT scans were acquired for each patient prior to the treatment (T1) and after treatment (T2) using the SkyView CBCT scanner (MyRay, Imola, Italy) at the following settings: 90 kVp, 10 mA, exposure time 6.88 seconds, 360° revolution and 0.23 mm voxel size. All scans were processed according to the protocol presented by CHO (15), where the 3D image is reoriented according to two reference planes, naso-frontozygomatic plane and Frankfort horizontal plane, to minimize errors from nonstandard head position.

Each CBCT scan was analyzed using DentalPlan (MyRay, Imola, Italy) software. Sagittal sections were generated automatically along the long axis (center of the root canal) of each lower incisor (Fig. 1A). Cementum-enamel junctions (CEJs) of the incisors were identified on the sagittal sections and the measurement levels were set at the distance of 3, 6, 9 and 12 mm in the apical direction from the CEJ. Finally, cross sectional images of individual incisors perpendicular to their long axis were obtained for each measurement level (Fig. 1B).

Labial cortical bone thickness was measured on these axial sections in the plane of the widest labiolingual root dimension (Fig. 2). This protocol provided eight measurements of the cortical bone thickness for each incisor, four at T1 and four at T2. The overall width of the alveolus in the same site was also measured. All measurements were taken by the same person.

Statistical analysis

All statistical analyses were performed using the Statistica 12 software (StatSoft Inc., Tulsa, Oklahoma, USA). Variables were checked for normal distribution by graphing the normal probability

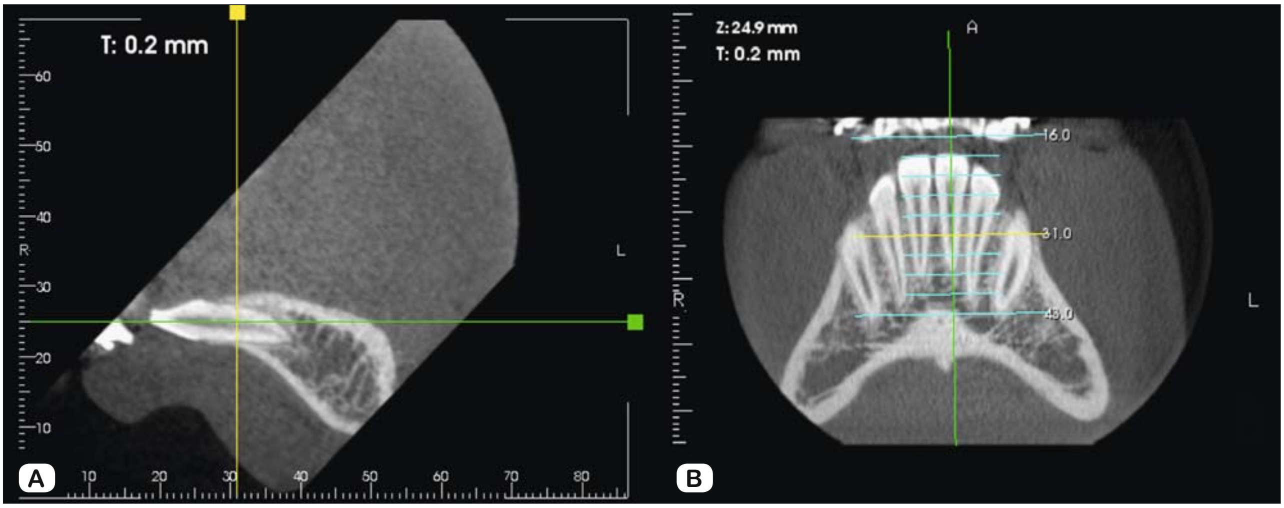

Fig. 1. Reconstruction of the sections in the long axis of the incisor. A. Sagittal section. B. Frontal view. Construction of the sections perpendicular to the long axis.

Tab. 1. Measurements obtained by cephalometric analysis before (T1) and after (T2) the treatment.

Variable	T1			T2			Mean difference	T-test
	Mean [mm]	SD [mm]	Range [mm]	Mean [mm]	SD [mm]	Range [mm]	T2–T1 (Δ) [mm]	p
IMPA (°)	92.60	7.04	79.6–107.6	98.40	7.13	85.8–113.0	5.80	0.000*
L1-APo (mm)	1.62	2.32	–2.3–4.9	3.85	2.00	0.2–8.3	2.23	0.000*

IMPA, incisor mandibular plane angle, L1-APo, position of the lower incisor relative to A-Pogonion line, *p < 0.05 (significant difference)

Tab. 2. Labial cortical bone thickness in each incisor before (T1) and after (T2) the treatment.

Mandibular incisor	T1			T2		Mean difference T2–T1 (Δ) [mm]	T-test p
	Measurement level [mm]	Bone thickness (SD) [mm]	Range [mm]	Bone thickness (SD) [mm]	Range [mm]		
Right lateral (42)	3	0.35 (0.22)	0.0–0.8	0.19 (0.13)	0.0–0.5	0.16	0.000*
	6	0.45 (0.16)	0.0–0.8	0.29 (0.20)	0.0–0.6	0.16	0.000*
	9	0.97 (0.37)	0.2–2.0	0.66 (0.41)	0.2–1.6	0.31	0.000*
	12	1.33 (0.40)	0.5–1.9	1.25 (0.57)	0.4–2.8	0.08	0.129
Right central (41)	3	0.35 (0.24)	0.0–0.8	0.24 (0.18)	0.0–0.5	0.11	0.001*
	6	0.40 (0.25)	0.0–1.1	0.29 (0.17)	0.0–0.8	0.11	0.020*
	9	0.90 (0.48)	0.2–2.2	0.76 (0.44)	0.0–1.6	0.14	0.003*
	12	1.23 (0.41)	0.5–2.4	1.17 (0.38)	0.5–2.0	0.06	0.015
Left central (31)	3	0.30 (0.23)	0.0–0.8	0.15 (0.15)	0.0–0.5	0.15	0.000*
	6	0.38 (0.23)	0.0–1.0	0.31 (0.46)	0.0–1.0	0.07	0.088
	9	0.86 (0.46)	0.2–1.6	0.70 (0.45)	0.2–2.0	0.16	0.004*
	12	1.22 (0.39)	0.5–2.1	1.15 (0.48)	0.2–2.5	0.07	0.123
Left lateral (32)	3	0.38 (0.36)	0.0–1.1	0.06 (0.13)	0.0–0.5	0.32	0.000*
	6	0.50 (0.22)	0.0–1.3	0.35 (0.21)	0.0–0.8	0.15	0.000*
	9	0.71 (0.33)	0.2–1.6	0.64 (0.39)	0.0–1.5	0.08	0.048*
	12	1.36 (0.39)	0.7–2.5	1.32 (0.38)	0.7–2.4	0.04	0.147

*p < 0.05 (significant difference)

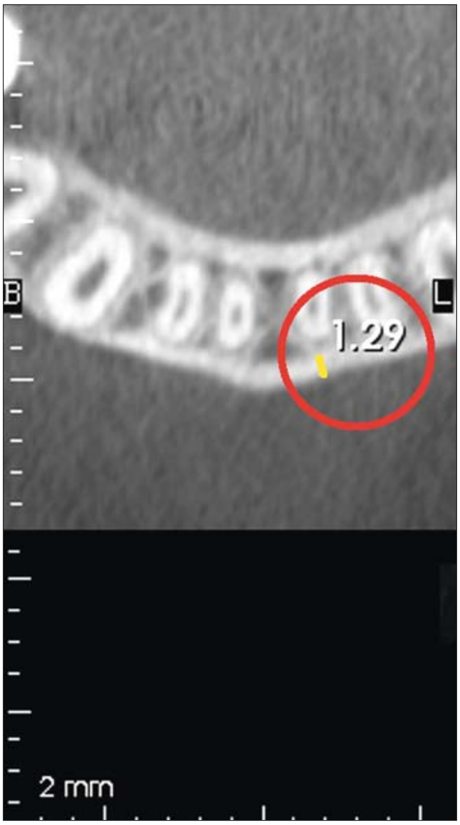

Fig. 2. Cortical bone thickness measurement at one level. Cortical thickness marked with the yellow line.

plot and using Kolmogorov-Smirnov test, revealing global insignificant departures from normality.

Descriptive statistics that included the average, standard deviation, and minimum and maximum values are provided for all the measured variables. The changes in the cephalometric measurements and in the cortical bone thickness after the treatment were evaluated using paired t-tests. Correlation analyses with Pearson correlation coefficient were used to determine the measure of association between the extent of the incisor movement and the extent of the bone loss.

The significance value of $p < 0.05$ was adopted for all the comparisons.

Results

No statistically significant differences were found between male and female subjects ($p > 0.05$), therefore the measurements obtained from male and female subjects were pooled in the final evaluation. The random method error ranged from 0.13 to 0.87 for all variables.

Cephalometric analysis

The results of T1 and T2 cephalometric measurements are listed in Table 1. There was a significant increase in IMPA where the mean difference after the treatment was 5.8° ($p < 0.001$). L1-APo) increased significantly by 2.23 mm after treatment ($p < 0.001$).

Tab. 3. Labial cortical bone thickness in all four incisors before (T1) and after (T2) the treatment.

Measurement level [mm]	T1		T2		Mean difference T2–T1 (Δ) [mm]	T-test p
	Bone thickness (SD) [mm]	Range [mm]	Bone thickness (SD) [mm]	Range [mm]		
3	0.35 (0.27)	0–1.1	0.16 (0.16)	0–0.5	0.19	0.000*
6	0.41 (0.23)	0–1.3	0.31 (0.21)	0–1.0	0.10	0.000*
9	0.83 (0.41)	0.2–2.2	0.69 (0.43)	0–2.0	0.14	0.000*
12	1.27 (0.40)	0.5–2.5	1.22 (0.45)	0.2–2.8	0.05	0.090*

*p < 0.05 (significant difference)

Tab. 4. Alveolus width in each incisor before (T1) and after (T2) the treatment.

Mandibular incisor	T1			T2		Mean difference T2–T1 (Δ) [mm]	T-test p
	Measurement level [mm]	Bone thickness (SD) [mm]	Range [mm]	Bone thickness (SD) [mm]	Range [mm]		
Right lateral (42)	3	7.11 (0.71)	5.7–8.8	7.13 (0.77)	5.9–8.5	–0.02	0.870
	6	7.05 (0.74)	5.4–8.6	6.98 (0.81)	5.4–9.0	0.07	0.507
	9	7.08 (1.44)	4.8–10.4	6.93 (1.50)	4.5–10.2	0.15	0.196
	12	7.22 (1.82)	4.1–11.1	7.17 (2.08)	3.6–11.9	0.05	0.710
Right central (41)	3	6.68 (0.95)	4.7–9.2	6.56 (0.84)	5.0–8.5	0.12	0.244
	6	6.71 (0.96)	4.4–8.8	6.71 (0.88)	5.1–8.5	0.00	0.975
	9	6.70 (1.4)	4.7–10.6	6.65 (1.29)	4.7–9.7	0.05	0.603
	12	7.45 (1.80)	4.3–11.4	7.19 (1.76)	4.5–11.3	0.27	0.018*
Left central (31)	3	6.70 (0.73)	5.2–7.8	6.60 (0.95)	4.8–8.4	0.10	0.368
	6	6.48 (0.95)	4.7–8.7	6.36 (0.81)	4.8–8.2	0.12	0.277
	9	6.78 (1.64)	4.8–10.9	6.54 (1.66)	4.1–9.7	0.24	0.012*
	12	7.28 (1.99)	4.5–12.0	7.13 (1.98)	4.4–11.1	0.15	0.084
Left lateral (32)	3	6.97 (0.64)	5.4–8.2	6.88 (1.02)	4.9–8.9	0.09	0.420
	6	7.14 (0.97)	5.0–8.7	7.15 (1.11)	5.2–10.4	–0.01	0.918
	9	6.85 (1.38)	4.2–10.3	6.80 (1.44)	4.5–10.4	0.03	0.822
	12	7.44 (1.70)	4.9–11.3	7.29 (1.82)	4.1–11.4	0.15	0.093

*p < 0.05 (significant difference)

Tab. 5. Labial cortical bone thickness in all four incisors before (T1) and after (T2) the treatment.

Measurement level [mm]	T1		T2		Mean difference T2–T1 (Δ) [mm]	T-test p
	Bone thickness (SD) [mm]	Range [mm]	Bone thickness (SD) [mm]	Range [mm]		
3	6.86 (0.75)	4.7–9.2	6.79 (0.92)	4.8–8.9	0.06	0.235
6	6.83 (0.93)	4.4–8.8	6.80 (0.96)	4.8–10.4	0.04	0.512
9	6.79 (1.43)	4.2–10.9	6.76 (1.48)	4.1–10.4	0.06	0.478
12	7.29 (1.79)	4.3–12.0	7.19 (1.9)	3.6–11.9	0.09	0.322

*p < 0.05 (significant difference)

CBCT analysis

The measurements of the cortical bone thickness for each incisor before and after orthodontic treatment are detailed in Table 2.

The bone thickness significantly decreased after the treatment at the 3-mm level for all four incisors: the mean difference was 0.16, 0.11, 0.15 and 0.32 mm in the teeth 42, 41, 31 and 32, respectively ($p < 0.01$ for all the measurements). The bone thickness also decreased significantly at the 6-mm level in the teeth 42, 41 and 32 (0.16, 0.11 and 0.15 mm, respectively) ($p < 0.001$, $p = 0.020$, $p < 0.001$, respectively). Bone decrease at the 6-mm measurement level in the left central incisor (0.07 mm) was not significant ($p = 0.088$). A significant decrease of the bone thickness at the 9-mm measurement level was found in all four incisors with mean differences of 0.31, 0.14, 0,16 and 0.08 mm in the teeth 42, 41, 31 and 32, respectively ($p < 0.001$, $p = 0.003$, 0.004 and 0.048, respectively). At the most apical level, 12 mm from the CEJ, the posttreatment decrease was significant only in right central incisor with the mean difference of 0.06 mm ($p = 0.015$). Changes found in the teeth 42, 31 and 32 did not reach significance ($p > 0.05$), with mean differences smaller than 0.1 mm.

The overall results for all four incisors together are shown in the Table 3. Statistically significant decrease of the cortical bone thickness was found in measurement levels 3, 6 and 9 mm ($p < 0.001$), with mean differences 0.19, 0.10 and 0.14 mm, respectively. Posttreatment change was not significant at 12 mm measurement level ($p = 0.090$), where the mean difference was as small as 0.05 mm.

The measurements of the width of the alveolus for each incisor before and after orthodontic treatment are presented in Table 4. The acquired values showed wide inter-individual variability.

Tab. 6. The analysis of correlation of the bone thickness change and the extent of the incisor movement.

Measurement level [mm]	IMPA	L1-APo
	R	R
3	–0.088	0.087
6	0.169	–0.242
9	0.062	–0.212
12	0.107	0.023

IMPA – incisor mandibular plane angle, L1-Apo – position of the lower incisor relative to A-Pogonion line,
R – Pearson correlation coefficient

The alveolar width changes were insignificant ($p > 0.05$) in all teeth at all the measurement levels with the exception of the 9-mm level in the tooth 31 ($p = 0.012$) and the 12-mm level in the tooth 41 ($p = 0.018$).

The overall results of alveolar width in all four incisors are shown in Table 5. Posttreatment change was not significant at any measurement level ($p > 0.05$), showing only an ambiguous trend for post-treatment alveolar width decrease.

Correlation analysis (Tab. 6) implies that there is no linear correlation between the cortical bone thickness change and IMPA changes. On the other hand, a weak negative correlation was found between bone thickness change and L1-APo change at the 6-mm and 9-mm measurement levels ($R = –0.242$ and $–0.212$, respectively). There were no correlations at the 3-mm and 12-mm measurement levels ($R = 0.087$ and 0.023).

Discussion

The imaging approach presented here provides a biologically plausible model of cortical alveolar bone remodeling and a basis for testable clinical predictions which, we hope, will aid in further pathophysiological and therapeutic research in this area. Our findings of a significant labial cortical bone loss after the proclination of the lower incisors are very much in keeping with some previous clinical reports (1, 4, 5, 7, 12–14, 16), underscoring the possible negative effects of this type of orthodontic treatment.

The remodeling of alveolar bone around the moving tooth during the treatment is one of the hallmarks of the physiology of orthodontics, with cortical bone creating a seemingly difficult-to-breach anatomical border to this movement (2). However, the decreasing initial thickness of the bone associated with degrading density (17) makes the thin layer of the cortical bone in incisor area particularly prone to microfractures during the orthodontic movement, resulting in bone loss (18). The selective inclusion of patients with crowding in this study and hence a specific type of movement may well explain the absence of significant changes of cortical bone thickness at the 12-mm measurement level, as the tooth apex did not change its position to such an extent to markedly affect the thickness of the surrounding bone. Moreover, and completely corresponding to our prior hypothesis, the thickness of the cortical bone at the measurement levels of 3, 6 and 9 mm was reduced in most cases.

Nonetheless, we may provide only conjectures on the extent the cortical bone loss is related to the bone volume before the treatment, as no formal correlation was found between the extent of the orthodontic movement and the bone loss in our analyses, possibly due to limited number of patients. Its average increase of 5.8° according to the cephalometric analysis was combined with an increase of L1-Apo distance by 2.33 mm on average, but both failed to show significant correlation with the bone loss extent.

Turning to the alveolar width change, our findings of minimal differences between the pretreatment and posttreatment value, under the resolution level of the device, also did not reach significance, which may be interpreted as a consequence of bone apposition on the lingual side during the proclination of the incisors. This result corresponds to the basic orthodontic axiom of bone remodeling around the tooth in the same extent during tooth movement (2).

Due to expected bone regeneration capacity, it would be expedient to continue with subsequent measurements in these patients in the retention phase. However, CBCT is usually not indicated at this stage.

An important point needs to be considered with regards to our results – the spatial resolution of the used imaging method. Several prior studies analyzed bone support of the incisors using various types of radiographs (1, 2, 4–7), but burdened with a major interference of the structure superimposition in the analysis of two-dimensional scans, bone loss tends to be underestimated in radiographs (19, 20). Computer tomography is able to provide precise information on the labio-lingual bone support (21, 23), resolving the above-described distortion and superimposition of the structures, with acceptable accuracy for this purpose in case of minimal bone thickness over 0.5 mm (24). This threshold, corresponding to 2–3 voxels in the scans, is very low, even when considering the tendency of CBCT to overestimate alveolar defects (25). From the clinical perspective, bone of this thickness can be considered a defect, hence not disproving the findings of our study. Nevertheless, higher resolution, though technically possible, is clearly precluded in the clinical practice due to medical and ethical concerns associated with increased radiation dose.

This approach represents a refinement and synthesis of ideas hypothesized in previous studies, pointing to marked proclination-induced disruption of cortical bone thickness in the areas close to the CEJ. Even though no correlation was found between the extent of orthodontic movement and the bone loss in our analyses, the possible lack of statistical power in this size of patient population does not allow us to proceed without due caution, mainly in patients with low initial bone thickness. Further prospective studies in well-defined patient populations will be necessary to elucidate this issue in its complexity.

References

1. Yared KF, Zenobio EG, Pacheco W. Periodontal status of mandibular central incisors after orthodontic proclination in adults. Am J Orthod Dentofacial Orthop 2006; 130: 6.e1–8.

2. Handelman CS. The anterior alveolus: Its importance in limiting orthodontic treatment and its influence on the occurrence of iatrogenic sequelae. Angle Orthod 1996; 66: 95–110.

3. Gracco A, Luca L, Bongiorno MC, Siciliani G. Computed tomography evaluation of mandibular incisor bony support in untreated patients. Am J Orthod Dentofacial Orthop 2010; 138: 179–187.

4. Mulie RM, Hoeve AT. The limitations of tooth movement within the symphysis, studied with laminagraphy and standardized occlusal films. J Clin Orthod 1976; 10: 882.

5. Melsen B, Allais D. Factors of importance for the development of dehiscences during labial movement of mandibular incisors: a retrospective study of adult orthodontic patients. Am J Orthod Dentofacial Orthop 2005; 127: 552–561.

6. Boyd RL, Leggott PJ, Quinn RS, Eakle WS, Chambers D. Periodontal implications of orthodontic treatment in adults with reduced or normal periodontal tissues versus those of adolescents. Am J Orthod Dentofacial Orthop 1989; 96: 191–198.

7. Årtun J, Krogstad O. Periodontal status of mandibular incisors following excessive proclination A study in adults with surgically treated mandibular prognathism. Am J Orthod Dentofacial Orthop 1987; 91: 225–232.

8. Rupprecht RD, Horning GM, Nicoll BK, Cohen ME. Prevalence of dehiscences and fenestrations in modern American skulls. J Periodontol 2001; 72: 722–729.

9. Larato D. Alveolar plate fenestrations and dehiscences of the human skull. Oral Surg Oral Med Oral Pathol 1970; 29: 816–819.

10. Leung CC, Palomo L, Griffith R, Hans MG. Accuracy and reliability of cone-beam computed tomography for measuring alveolar bone height and detecting bony dehiscences and fenestrations. Am J Orthod Dentofacial Orthop 2010; 137: S109–119.

11. Evangelista K, De Faria Vasconcelos K, Bumann A, Hirsch E, Nitka M, Silva MAG. Dehiscence and fenestration in patients with Class I and Class II Division 1 malocclusion assessed with cone-beam computed tomography. Am J Orthod Dentofacial Orthop 2010; 138: 133–e1.

12. Wehrbein H, Bauer W, Diedrich P. Mandibular incisors, alveolar bone, and symphysis afterorthodontic treatment. A retrospective study. Am J Orthod Dentofacial Orthop 1996; 110: 239–246.

13. Sarikaya S, Haydar B, Ciğer S, Ariyürek M. Changes in alveolar bone thickness due to retraction of anterior teeth. Am J Orthod Dentofacial Orthop 2002; 122: 15–26.

14. Lupi JE, Handelman CS, Sadowsky C. Prevalence and severity of apical root resorption and alveolar bone loss in orthodontically treated adults. Am J Orthod Dentofacial Orthop 1996; 109: 28–37.

15. Cho HJ. A three-dimensional cephalometric analysis. J Clin Orthod 2009; 43: 235–252.

16. Garlock DT, Buschang PH, Araujo EA, Behrents RG, Kim KB. Evaluation of marginal alveolar bone in the anterior mandible with pretreatment and posttreatment computed tomography in nonextraction patients. Am J Orthod Dentofacial Orthop 2016; 149: 192–201.

17. Bresin A, Kiliaridis S, Strid KG. Effect of masticatory function on the internal bone structure in the mandible of the growing rat. Eur J Oral Sci 1999; 107: 35–44.

18. Taylor D, Lee TC. Microdamage and mechanical behaviour: predicting failure and remodelling in compact bone. J Anat 2003; 203: 203–211.

19. Lang NP, Hill RW. Radiographs in periodonties. J Clin Periodontol 1977; 4: 16–28.

20. Fuhrmann R. Dreidimensionale Interpretation von alveolären Knochendehiszenzen. J Orofac Orthop 1996; 57: 62–74.

21. Davis GR, Wong FSL. X-ray microtomography of bones and teeth. Physiol Meas 1996; 17: 121.

22. Freisfeld M, Schüller H. Anwendungsmöglichkeiten der Computertomographie in der Kieferorthopädie. Prakt Kieferorthop 1992; 6: 169–182.

23. Patcas R, Müller L, Ullrich O, Peltomäki T. Accuracy of cone-beam computed tomography at different resolutions assessed on the bony covering of the mandibular anterior teeth. Am J Orthod Dentofacial Orthop 2012; 141: 41–50.

24. Fuhrmann RAW, Wehrbein H, Langen HJ, Diedrich PR. Assessment of the dentate alveolar process with high resolution computed tomography. Dentomaxillofac Radiol 1995; 24: 50–54.

25. Sun L, Zhang L, Shen G, Wang B, Fang B. Accuracy of cone-beam computed tomography in detecting alveolar bone dehiscences and fenestrations. Am J Orthod Dentofacial Orthop 2015; 147: 313–323.

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