Original Article

Measurement of the midpalatal suture width

A comparison of flat-panel volume computed tomography to histomorphometric analysis in a porcine model

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ABSTRACT

Objective: To conduct a pilot study to investigate the potentiality to determine the midpalatal sutural width radiographically with a flat-panel volume computed tomography (fpVCT) in a porcine model.

Materials and Methods: Bone samples from the midpalatal suture of five young (16 weeks) and five old (200 weeks) *sus scrofa domestica* were gathered. The midpalatal suture width was measured via fpVCT and compared to respective histological preparations. Results with $P < .05$ were considered significant.

Results: The data obtained by fpVCT and by histomorphometric analysis reveal a highly significant age dependency of the measured suture width (both $P < .0001$), with lower suture width values in older subjects compared to the younger group. The averaged suture widths measured in the fpVCT images shows a distinctively higher mean compared to the histomorphometric data with high statistical significance ($P < .0001$). The evaluated difference between both methods was almost constant.

Conclusion: fpVCT is a powerful tool for determining midpalatal sutural width. (*Angle Orthod.* 2012;82:145–150.)

KEY WORDS: Midpalatal suture; fpVCT; Histomorphometric analysis; Porcine

INTRODUCTION

Rapid maxillary expansion (RME) represents a well-proven method for treatment of maxillary transverse deficiency. Nevertheless, it can generate several problems in skeletally mature patients, such as fenestration of the buccal cortex, root resorption, lateral tipping of the teeth, and, finally, the inability to open the midpalatal suture.[1,2] To date, the decision of whether to use surgically assisted RME (SARME) has been an age-based one, although no reliable correlation between chronological age and changes in the midpalatal suture in skeletally mature patients exists.[3] Since SARME results in a higher morbidity than conventional RME,[4,5] finding ways to determine if and to what extend the expansion of the maxillary complex will need surgical assistance or not is important to reducing the potential risks for the patient.[6]

A decrease in the midpalatal suture width, which can be age and functional related,[7–9] is a potential prognostic factor for an increase of the resistance against conventional RME.[10–12] For this reason, searching for a radiological device that solidly visualizes the midpalatal suture complex and enables one to measure the suture width is essential to the therapeutic approach.

As reported by Wehrbein and Yildizhan,[13] the occlusal radiograph is not a reliable method with which

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to define the suture structure. Multislice spiral computed tomography (MSCT) has generally improved diagnostic imaging possibilities in medicine.[14,15] The prototype of a flat-panel detector-based volumetric computed tomography (fpVCT) demonstrates an increase in spatial resolution and improves the evaluation of detailed skeletal and dental structures.[16–18] It has already been reported[16,19] that fpVCT is superior to the MSCT with regard to visualization of the sutural structures.

The aim of the present pilot study was to analyze the sutural width via fpVCT compared to the respective histological preparations in a porcine model.

MATERIALS AND METHODS

For the investigation palate specimens from five young (aged 12–18 weeks) and five old (aged 128–208 weeks) *Sus scrofa domestica*, German land race, were used. After sacrificing the animals, the maxillae were removed and the palatine mucosa was detached. Along the midpalatal suture line, six cylindric bone samples with a diameter of 1 cm were obtained and fixed in 4% buffered formaldehyde solution at ambient temperature.

All imaging was performed with the fpVCT prototype (General Electric Global Research, Niskayuna, NY), which comprised two flat-panel x-ray detectors based on amorphous silicon, with a dimension of 20.5 × 20.5 cm and with 1024 × 1024 pixels. The pixel size amounted to 200 × 200 μm, with a radiographic enlargement of 1.43 that created a resolution of 140 μm. All data were generated with the same protocol, which has been described in detail elsewhere.[19] To explore the data sets, we used the voxtool 3.0.64u software implemented on an Advantage Workstation 4.2 (GE HealthCare, Chalfont, St. Giles, UK).

For further analysis the data sets were displayed as facial slices perpendicular to the suture and the palatal bone surface. This area was marked with a line on the palatal surface of a volume-rendering image of the respective specimen via the software. The line was oriented perpendicularly to the suture, as identifiable at the palatal bony surface. The image of the volume rendering with the reference line drawn in was stored as a reference image for the histological preparation. Six width measurements equally distributed along the suture were performed in the reference image plane.

The two observers were unaware of the experimental design and underwent standardized preparatory training. The images were evaluated in a randomized order regardless of the age of the specimens.

For the histological analysis the obtained bone specimens were embedded in methyl methacrylate (Technovit 9100, Heraus Kulzer, Hanau, Germany). In the reference plane parallel sections with a thickness of 5–7 μm were prepared using a LEICA RM 2165 microtome. For the histomorphometric analysis the sections were stained with alizarin/methylene blue.[20] For the measurement of the sutural width in the histological images the software Axio Vision combined with a microscope, Axioskop 2 plus/Axio Cam MRc5 (Carl Zeiss, Oberkochen), was used. The measurements were carried out by the two observers in the same way described for the fpVCT images.

Statistical Analysis

Data were analyzed using SAS 9.1 software (SAS Institute Inc, Cary, NC). For analyzing the fpVCT measurements and the histomorphometric data, an analysis of variance with the factors age (young vs old), method (fpVCT vs histomorphometry), and reader (1 vs 2) was carried out. Results with levels of $P < .05$ were considered significant.

The Animal Protection Official at Goettingen University granted institutional approval for this study.

RESULTS

In general, the observations revealed differences between the younger and the older animals in the suture anatomy according to the course of the suture, with a higher interdigitation and smaller suture width in the old age group (Figure 1). Furthermore, the bony structures appear to be more compact in the older group. In the fpVCT images and in the histological sections a closure of the suture or obliterations in the suture line, respectively, could not be observed. The average values for the parameter "suture width" for the young and the old age groups via fpVCT and histomorphometric analysis are shown in Table 1.

The data obtained by fpVCT as well as by histomorphometric analysis reveal a highly significant age dependency of the measured suture width (both $P < .0001$), with lower suture width values in older subjects (compared to the younger group).

The averaged suture widths measured in the fpVCT images show a distinctively higher mean compared to the histomorphometric data (young group = 0.25 mm vs 0.18 mm; old group = 0.15 mm vs 0.10 mm), with high statistical significance ($P < .0001$) (Figures 2 and 3).

The reader shows no significant influence in the fpVCT group ($P = .311$) or in the histomorphometry ($P = .235$) group.

DISCUSSION

SARME is a common treatment procedure that becomes necessary in numerous, especially adult, patients.[6,21] However, it may cause severe complications.[4,22]

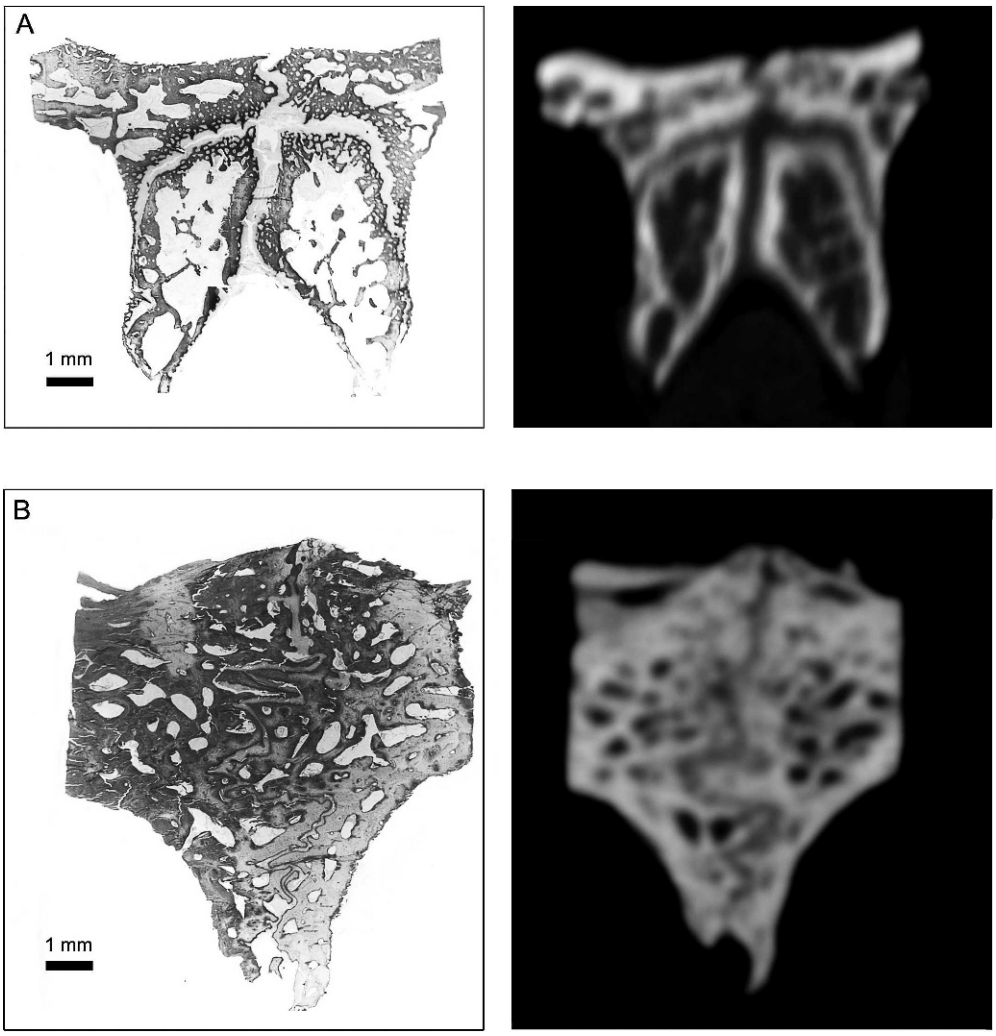

Figure 1. Facial slices from the bone samples of a young (A) and an old (B) animal and the respective histological preparations.

There is controversy with regard to which age is required for SARME, since many authors[23–25] have shown successful nonsurgical RME in adults as well. Therefore, finding a congruent diagnostic procedure to indicate SARME is essential but not yet possible.[26] However, most studies[6,10–12] show that age-correlated morphological changes of the midface go along with an increased resistance against conservative RME, which necessitates SARME. Unfortunately, until today it has not been possible, especially in the borderline age group of 19–20 years,[21,26] to identify patients who will need SARME before expansion, since anatomical changes of the midpalatal suture are subject to a considerably high interindividual variability and are not only correlated with the chronological age.[3] Hand wrist radiographs typically used for the evaluation of skeletal maturity are not indicative for estimation of the condition in the midpalatal suture.[27,28] The assumption that the total obliteration in the midpalatal suture in adults is the main factor for the increasing resistance in adult patients[29,30] lacks evidence but is still popular in the actual literature.[6,21]

Table 1. Comparison of the Suture Width in the Younger and Older Age Groups Determined by Flat-Panel Volume Computed Tomography (fpVCT) and Histomorphometry

Method	Age	Minimum, mm	Maximum, mm	Mean
fpVCT	Young	0.11	0.53	0.25
	Old	0.09	0.29	0.15
Histomorphometry	Young	0.08	0.63	0.18
	Old	0.01	0.27	0.10

Knaup et al.[8] found significant differences in the human midpalatal suture width between younger and older subjects. These findings correlate well with the radiological and histological observations made in our study. We found highly significant differences in mean values of the suture width between the younger and the older groups, with no parts of obliteration in the midpalatal suture. A previous three-dimensional

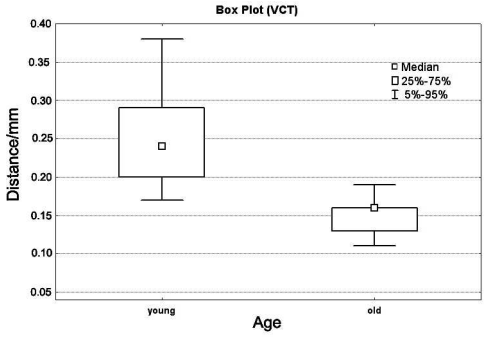

Figure 2. Suture width determined by flat-panel volume computed tomography (fpVCT).

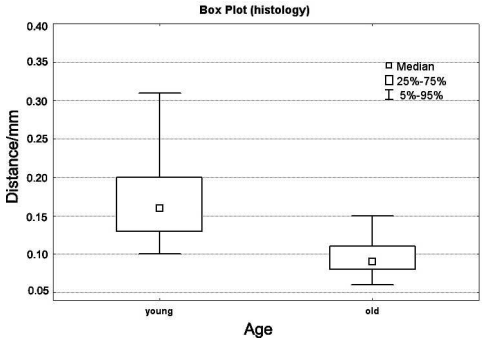

Figure 3. Suture width determined by histomorphometry.

micro-CT study[27] demonstrated an increase in bone density in the region of the midpalatal suture in older subjects. According to these findings as well as to the observations made in the present study, the morphological changes in the condition of the sutural complex and the changes in the bony structures connected to the maxilla presumably cause the increase in resistance against the expansion force in older subjects.[10,27,31] In addition to this, a functional influence on the sutural bone apposition and the general cranial suture morphology was demonstrated in many studies.[7,32–34] In this context, Katsaros et al.[7] revealed that a reduced masticatory function caused by a soft diet is accompanied by less bone apposition in the facial sutures of rats. Since many authors found that craniofacial morphology affects the bite force with, for example, smaller values for the long-faced type,[35,36] a different strategy in maxillary transverse deficiency therapy for different craniofacial morphologies is reasonable. Taking age-dependent morphology as well as functional changes of the midpalatal suture into consideration, it appears to be meaningful to identify an easy-to-determine parameter with which to predict the feasible resistance against conventional RME. The parameter ''suture width,'' dependent on both function and age, is possibly of high prognostic value for the therapeutic strategy. According to the sutural anatomy, humans and pigs show comparable characteristics,[37] so that the data acquired in pigs in the present study most likely show a high similarity to data in humans.

The present study shows that precise data from the sutural complex can be obtained with fpVCT. Numerous studies[17,38–40] substantiate the good diagnostic capabilities of fpVCT for small bone structures. Obenauer et al.[41] demonstrated that with the prototype of a fpVCT the imaging of different phantoms can be distinctively improved in comparison to the results afforded by MSCT.

Micro-CT allows a high local resolution of 5–50 μm and is an appropriate system for nondestructive visualization of fine bone architecture.[42] It was used to evaluate animal and human craniofacial sutures, but micro-CT studies[27,43,44] limited the sample size to approximately 1 cm and are therefore not applicable.

There are only very few comparative studies concerning radiological and histomorphometric analysis of suture preparations.[13,44] Recinos et al.[44] revealed a major morphological consistency with minor changes in the same structures of micro-CT images with histological sections of murine sutures. The authors saw a possible explanation for these differences in the fact that incompletely calcified regions may not be identified as fused with micro-CT because of their lower tissue density. The observed differences between fpVCT images and histomorphometric analyses in the present study could be explicable in the same manner. On average, we found distinctively smaller differences in suture width within the histological sections than in the respective fpVCT images. This could be explained by a reduced calcification of the bony sutural borderline adjacent to the sutural lumina, which can therefore not be correctly depicted by fpVCT. Crucial for the measurement of the suture widths is the identification of the bone-suture interface. As a result of the resolution of the fpVCT of about 0.150 mm, the bone border is blurred within this dimension as a result of the partial volume effect. To compensate for that, we used a threshold for bone segmentation of 60 HU, which is the average of the bone density and the density of the liquid inside the suture. The threshold was kept constant in all analyses; therefore, only the same absolute error is added to the results. Suture distances measured in the fpVCT data sets all appeared larger than the results obtained with histology, indicating that the threshold was chosen a little bit too high, which yielded overestimation of the partial volume effect with respect to the bone. Additionally, the differences result from the fact that the virtual sections of the fpVCT are thicker than the sections used for the histomorphometric analysis, causing a considerable decrease in resolution.[32] Nevertheless, the present pilot study demonstrates that fpVCT is capable of determining the midpalatal suture width highly reliably within the

examined different age groups, although the exact values do not always correspond to those obtained histomorphometrically.

The fpVCT tool used is a computed tomographic modality that until now has not been available for patient scanning because of the lack of variable collimation of the x-ray tube.[41] In the available literature cone-beam CT technology is described by several author[45–47] as a means to examine RME effects;[48,49] however, the morphological appearance of the suture structure itself or measurements of the width has not been described before.

CONCLUSIONS

- With fpVCT it is possible to determine the suture width in younger and older age groups of a porcine model. A closure of the suture or obliterations in the suture line could not be observed in either the young or the old age groups.
- Since the factor suture width is of possible prognostic value, changes in the therapeutic approach concerning the SARME are possible.

REFERENCES

1. Timms DJ, Moss JP. An histological investigation into the effects of rapid maxillary expansion on the teeth and their supporting tissues. *Trans Eur Orthod Soc*. 1971:263–271.
2. Wertz RA. Skeletal and dental changes accompanying rapid midpalatal suture opening. *Am J Orthod*. 1970;58:41–66.
3. Mann RW, Jantz RL, Bass WM, Willey PS. Maxillary suture obliteration: a visual method for estimating skeletal age. *J Forensic Sci*. 1991;36:781–791.
4. Lanigan DT, Mintz SM. Complications of surgically assisted rapid palatal expansion: review of the literature and report of a case. *J Oral Maxillofac Surg*. 2002;60:104–110.
5. Suri L, Taneja P. Surgically assisted rapid palatal expansion: a literature review. *Am J Orthod Dentofacial Orthop*. 2008; 133:290–302.
6. Chrcanovic BR, Custodio AL. Orthodontic or surgically assisted rapid maxillary expansion. *Oral Maxillofac Surg*. 2009;13:123–137.
7. Katsaros C, Zissis A, Bresin A, Kiliaridis S. Functional influence on sutural bone apposition in the growing rat. *Am J Orthod Dentofacial Orthop*. 2006;129:352–357.
8. Knaup B, Yildizhan F, Wehrbein H. Age-related changes in the midpalatal suture. A histomorphometric study. *J Orofac Orthop*. 2004;65:467–474.
9. Melsen B. Palatal growth studied on human autopsy material. A histologic microradiographic study. *Am J Orthod*. 1975;68:42–54.
10. Holberg C, Steinhauser S, Rudzki-Janson I. Rapid maxillary expansion in adults: cranial stress reduction depending on the extent of surgery. *Eur J Orthod*. 2007;29:31–36.
11. Koudstaal MJ, Wolvius EB, Schulten AJ, Hop WC, van der Wal KG. Stability, tipping and relapse of bone-borne versus tooth-borne surgically assisted rapid maxillary expansion; a prospective randomized patient trial. *Int J Oral Maxillofac Surg*. 2009;38:308–315.
12. Schimming R, Feller KU, Herzmann K, Eckelt U. Surgical and orthodontic rapid palatal expansion in adults using Glassman's technique: retrospective study. *Br J Oral Maxillofac Surg*. 2000;38:66–69.
13. Wehrbein H, Yildizhan F. The mid-palatal suture in young adults. A radiological-histological investigation. *Eur J Orthod*. 2001;23:105–114.
14. Fuhrmann A, Schulze D, Rother U, Vesper M. Digital transversal slice imaging in dental-maxillofacial radiology: from pantomography to digital volume tomography. *Int J Comput Dent*. 2003;6:129–140.
15. Habersack K, Karoglan A, Sommer B, Benner KU. High-resolution multislice computerized tomography with multiplanar and 3-dimensional reformation imaging in rapid palatal expansion. *Am J Orthod Dentofacial Orthop*. 2007;131:776–781.
16. Cheung AC, Bredella MA, Al Khalaf M, Grasruck M, Leidecker C, Gupta R. Reproducibility of trabecular structure analysis using flat-panel volume computed tomography. *Skeletal Radiol*. 2009;38:1003–1008.
17. Hannig C, Dullin C, Hulsmann M, Heidrich G. Three-dimensional, non-destructive visualization of vertical root fractures using flat panel volume detector computer tomography: an ex vivo in vitro case report. *Int Endod J*. 2005;38:904–913.
18. Obenauer S, Dullin C, Alves F, Missbach-Guentner J, Grabbe E, Heuser M. Flat-panel-detector-based volumetric CT: performance evaluation of imaging for skeletal structures of small animals in comparison to multislice CT. *Clin Imaging*. 2007;31:18–22.
19. Hahn W, Fricke-Zech S, Fialka-Fricke J, et al. Imaging of the midpalatal suture in a porcine model: flat-panel volume computed tomography compared with multislice computed tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2009;108:443–449.
20. Smith LG, Karagianes MT. Histological preparation of bone to study ingrowth into implanted materials. *Calcif Tissue Res*. 1974;14:333–337.
21. Altug Atac AT, Karasu HA, Aytac D. Surgically assisted rapid maxillary expansion compared with orthopedic rapid maxillary expansion. *Angle Orthod*. 2006;76:353–359.
22. Koudstaal MJ, Poort LJ, van der Wal KG, Wolvius EB, Prahl-Andersen B, Schulten AJ. Surgically assisted rapid maxillary expansion (SARME): a review of the literature. *Int J Oral Maxillofac Surg*. 2005;34:709–714.
23. Capelozza Filho L, Cardoso Neto J, da Silva Filho OG, Ursi WJ. Non-surgically assisted rapid maxillary expansion in adults. *Int J Adult Orthod Orthognath Surg*. 1996;11:57–66, discussion 67–70.
24. Handelman CS. Nonsurgical rapid maxillary alveolar expansion in adults: a clinical evaluation. *Angle Orthod*. 1997;67: 291–305, discussion 306–308.
25. Stuart DA, Wiltshire WA. Rapid palatal expansion in the young adult: time for a paradigm shift? *J Can Dent Assoc*. 2003;69:374–377.
26. Korbmacher H, Huck L, Merkle T, Kahl-Nieke B. Clinical profile of rapid maxillary expansion—outcome of a national inquiry. *J Orofac Orthop*. 2005;66:455–468.
27. Korbmacher H, Schilling A, Puschel K, Amling M, Kahl-Nieke B. Age-dependent three-dimensional microcomputed tomography analysis of the human midpalatal suture. *J Orofac Orthop*. 2007;68:364–376.
28. Revelo B, Fishman LS. Maturational evaluation of ossification of the midpalatal suture. *Am J Orthod Dentofacial Orthop*. 1994;105:288–292.
29. Haas AJ. The treatment of maxillary deficiency by opening the midpalatal suture. *Angle Orthod*. 1965;35:200–217.
30. Pirelli P, Botti F, Ragazzoni E, Arcuri C, Cocchia D. A light microscopic investigation of the human midpalatal suture. *Ital J Anat Embryol*. 1999;104:11–18.

31. Kusakabe T, Caputo AA, Shetty V, Iida J. Biomechanical rationale for surgically facilitated expansion of the maxilla in the cleft palate patient. *World J Orthod*. 2007;8:167–173.
32. Abed GS, Buschang PH, Taylor R, Hinton RJ. Maturational and functional related differences in rat craniofacial growth. *Arch Oral Biol*. 2007;52:1018–1025.
33. Byron CD, Borke J, Yu J, Pashley D, Wingard CJ, Hamrick M. Effects of increased muscle mass on mouse sagittal suture morphology and mechanics. *Anat Rec A Discov Mol Cell Evol Biol*. 2004;279:676–684.
34. Saito K, Shimizu Y, Ooya K. Age-related morphological changes in squamous and parietomastoid sutures of human cranium. *Cells Tissues Organs*. 2002;170:266–273.
35. Ingervall B, Minder C. Correlation between maximum bite force and facial morphology in children. *Angle Orthod*. 1997; 67:415–422, discussion 423–424.
36. Koc D, Dogan A, Bek B. Bite force and influential factors on bite force measurements: a literature review. *Eur J Dent*. 2010;4:223–232.
37. Gedrange T, Kobel C, Harzer W. Hard palate deformation in an animal model following quasi-static loading to stimulate that of orthodontic anchorage implants. *Eur J Orthod*. 2001;23:349–354.
38. Hahn W, Fricke-Zech S, Fricke J, et al. Detection and size differentiation of simulated tooth root defects using flat-panel volume computerized tomography (fpVCT). *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2009;107:272–278.
39. Reichardt B, Sarwar A, Bartling SH, et al. Musculoskeletal applications of flat-panel volume CT. *Skeletal Radiol*. 2008; 37:1069–1076.
40. Sehmisch S, Dullin C, Zaroban A, et al. The use of flat panel volumetric computed tomography (fpVCT) in osteoporosis research. *Acad Radiol*. 2009;16:394–400.
41. Obenauer S, Dullin C, Heuser M. Flat panel detector-based volumetric computed tomography (fpVCT): performance evaluation of volumetric methods by using different phantoms in comparison to 64-multislice computed tomography. *Invest Radiol*. 2007;42:291–296.
42. Ruegsegger P, Koller B, Muller R. A microtomographic system for the nondestructive evaluation of bone architecture. *Calcif Tissue Int*. 1996;58:24–29.
43. Engelke K, Karolczak M, Lutz A, Seibert U, Schaller S, Kalender W. Micro-CT. Technology and application for assessing bone structure [in German]. *Radiologe*. 1999;39:203–212.
44. Recinos RF, Hanger CC, Schaefer RB, Dawson CA, Gosain AK. Microfocal CT: a method for evaluating murine cranial sutures in situ. *J Surg Res*. 2004;116:322–329.
45. Ballanti F, Lione R, Baccetti T, Franchi L, Cozza P. Treatment and posttreatment skeletal effects of rapid maxillary expansion investigated with low-dose computed tomography in growing subjects. *Am J Orthod Dentofacial Orthop*. 2010;138:311–317.
46. Christie KF, Boucher N, Chung CH. Effects of bonded rapid palatal expansion on the transverse dimensions of the maxilla: a cone-beam computed tomography study. *Am J Orthod Dentofacial Orthop*. 2010;137(suppl):S79–S85.
47. Franchi L, Baccetti T, Lione R, Fanucci E, Cozza P. Modifications of midpalatal sutural density induced by rapid maxillary expansion: a low-dose computed-tomography evaluation. *Am J Orthod Dentofacial Orthop*. 2010;137: 486–488, discussion 412A–413A.
48. da Silva Filho OG, Lara TS, de Almeida AM, da Silav HC. Evaluation of the midpalatal suture during rapid palatal expansion in children: a CT study. *J Clin Pediatr Dent*. 2005; 29:231–238.
49. Tausche E, Deeb W, Hansen L, Hietschold V, Harzer W, Schneider M. CT analysis of nasal volume changes after surgically-assisted rapid maxillary expansion. *J Orofac Orthop*. 2009;70:306–317.