Presurgical Planning in Implant Restorations: Correct Interpretation of Cone-Beam Computed Tomography for Improved Imaging

S. KOURTIS, DDS, Dr.Dent.*, **E. SKONDRA,** DDS†, **I. ROUSSOU,** DDS, MSc, Dr.Dent.‡, **E.V. SKONDRAS,** DDS§

ABSTRACT

Contemporary implant dentistry is a primarily prosthetically driven treatment. The implant position is defined during the diagnostic phase, and the radiographic guide (template) indicates accurately the area of concern on the cone-beam computed tomography (CBCT). CBCT is an essential diagnostic key to a successful treatment plan in many cases.

The aim of this paper was to underline the importance of proper alignment of the scanning levels in CBCT in order to avoid distorted cross-sectional images.

As demonstrated with two clinical cases in this preliminary study, the initial scanning images of the CBCT must be drawn parallel to the occlusal plane, as defined by the diagnostic wax-up of the final restoration. The radiographic template offers valuable information about the planned location and inclination of the implant and the restoration. Proper image reconstruction following the dental scan can contribute significantly to accurate cross-sectional images and detailed presurgical planning.

CLINICAL SIGNIFICANCE

CBCT is important for presurgical planning in many implant cases. Although the precision of computer tomography in dentistry has been documented in experimental studies, the influence of the inclination of the scanning level to the accuracy of the cross-sectional images has not been clearly shown. Using the occlusal plane as a reference point can result in more accurate cross-sectional images.

(J Esthet Restor Dent 24:321–334, 2012)

INTRODUCTION

Although three-dimensional (3D) imaging technologies in dentistry have been available since the early 1990s, clinicians now have much greater access to improved diagnostic procedures for detailed presurgical evaluation of the bone substrate prior to implant insertion. In the past, only panoramic X-rays were used for this purpose, but both magnification and distortion of the image do not allow accurate presurgical examination.[1] Furthermore, the panoramic radiograph is a two-dimensional image, and no information can be obtained concerning the buccal–lingual anatomy or width of the alveolar crest. For successful implant treatment, it is important for the clinician to identify anatomical structures plus height, width, and angulation of the residual alveolar ridge. Clinical examination and panoramic X-ray offer useful information for initial evaluation, but in many cases, 3D imaging will provide more accurate planning.[2]

*Assistant Professor, Department of Prosthodontics, Dental School, National and Kapodestrian University of Athens, Athens, Greece
†Postgraduate student, Department of Prosthodontics, Dental School, National and Kapodestrian University of Athens, Athens, Greece
‡Lecturer, Department of Prosthodontics, Dental School, National and Kapodestrian University of Athens, Athens, Greece
§Dentist, Private Practice, Athens, Greece

 DOI 10.1111/j.1708-8240.2012.00505.x

Dental computer tomography (CT) scan and cone-beam computed tomography (CBCT) allow precise evaluation of the bone anatomy and accurate assessment to critical anatomic landmarks.[3–5] Furthermore, pathology such as tumors, cysts, infections, inflammatory lesions, and some fractures can be visualized.

Over the past couple of decades, the literature has referred to the concept of "prosthetically driven implantology."[6,7] With this concept, the implant position is planned during the diagnostic phase according to the desired prosthetic restoration.[8] A radiographic guide (template) is fabricated to indicate precisely the area of restoration on the 3D scan, usually CBCT imaging. The template is made of acrylic resin as a duplicate from the diagnostic wax-up of the shape of the planned final restoration which is essential for predicting esthetic and functional results.

Many types of radiographic guides (templates) have been reported in the literature for single or multiple implants.[9–14] The template must be rigid and resistant to deformation during disinfection or surgical procedures. The design of the template should allow insertion and removal for the radiographic examination and surgery. Therefore, the stability of the template either in occlusion or in open-mouth position must be evaluated, as it is essential for detailed and undistorted images.[8] Radiopaque materials such as gutta-percha, metal balls, barium sulfate, etc. are incorporated in the template to indicate the relationship of the final prosthesis to the bone substrate.[15] When a material such as barium sulfate is processed in the acrylic resin templates, the outline of the planned restoration is imaged in relation to the bone on the CBCT.[16] In that case, the need for bone augmentation or other treatment planning considerations can be recognized presurgically.

From the CBCT, performed with an accurate radiographic guide, the following information may be obtained:[8]

1 density, height, and width of the residual alveolar ridge
2 vital anatomical structures related to the surgical area
3 eventual need for horizontal or vertical augmentation

The information obtained by the CBCT can guide the clinicians to the selection of an appropriate implant, regarding length, diameter, and inclination. The relation of the planned restoration to the residual ridge can be recognized.

After CBCT imaging with the radiographic template, the scanning levels are then determined. These data are used for the 3D reconstruction of the bone substrate, and cross-sectional images are produced depicting the alveolar ridge. The inferior border of the mandible has previously been used as an orientation line, because it is an easily recognizable anatomic landmark, both in patients with remaining teeth or completely edentulous.[4,17] More appropriately, the occlusal plane of the patient can be used for the CBCT, if it can be recognized.[18]

Most available dental CBCT programs are based on panoramic images that are combined for the visual reconstruction of the bone substrate. From the digital reconstruction, consecutive cross-sectional images are produced with predetermined thickness (usually 1–2 mm). Ideally, the cross-sectional images should be perpendicular to the alveolar ridge, representing the bone substrate along the implant axis.

Aim

The aim of this paper was to underline the importance of proper alignment of the scanning levels in CBCT to avoid distorted images.

CASE PRESENTATIONS

Case A

A 50-year-old white male patient was referred for prosthetic restoration to the Postgraduate Clinic of the

DOI 10.1111/j.1708-8240.2012.00505.x

Department of Prosthodontics, University of Athens. The treatment included full-mouth rehabilitation with implant restorations.

The final treatment plan for the maxilla included single implant crowns on the right side in areas of teeth #3 and 5 and a fixed partial denture on the left side on teeth #11 and 13. In the mandible, on the left side, the second molar (tooth #18) had a doubtful prognosis. For this reason, single crowns for teeth #21 and 18 and an implant supported fixed partial denture for the regions of teeth #19 and 20 were planned. On the right side two single implant crowns for areas of the second premolar and first molar (teeth #29 and 30) were planned. The extended edentulous area in the mandibular left side area (#18–21) dictated an additional premolar between implants #19 and 20 as a pontic (**Figure 1**).

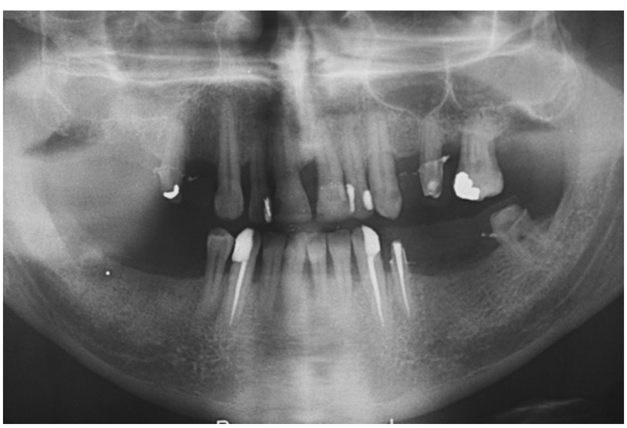

FIGURE 1. Case A: initial radiographic examination.

Radiographic templates were fabricated as duplicates from the diagnostic wax-up. At the initial stage, the templates were formed by heat and vacuum from a thermoplastic sheet in an Omnivac (Omnivac sheet, Dentsply Raintree Essix Co., Sarasota, FL, USA) device. The templates were removed and placed over the initial study casts to verify proper fit. The hollow space of the teeth in the template was filled with translucent autopolymerizing acrylic resin and was fitted on the initial stone cast. The outer surfaces of the teeth on the template were covered with radiopaque material (amalgam powder diluted in transparent nail varnish) to indicate the contour of the planned restoration on the CT scan. Gutta-percha points were inserted in the center of the acrylic teeth along the planned implant axis. Following polymerization of the resin, the template was trimmed and tried on the patient to verify effortless insertion and proper fit (**Figure 2**).

The patient was referred for a CBCT to the Department of Oral and Maxillofacial Radiology of the Dental School, University of Athens with the radiographic template in situ. The desired shape of the planned restoration and its relation to the bone substrate could be clearly recognized. Furthermore, inclination, length, and diameter of the desired implants could be selected. For the mandibular left second

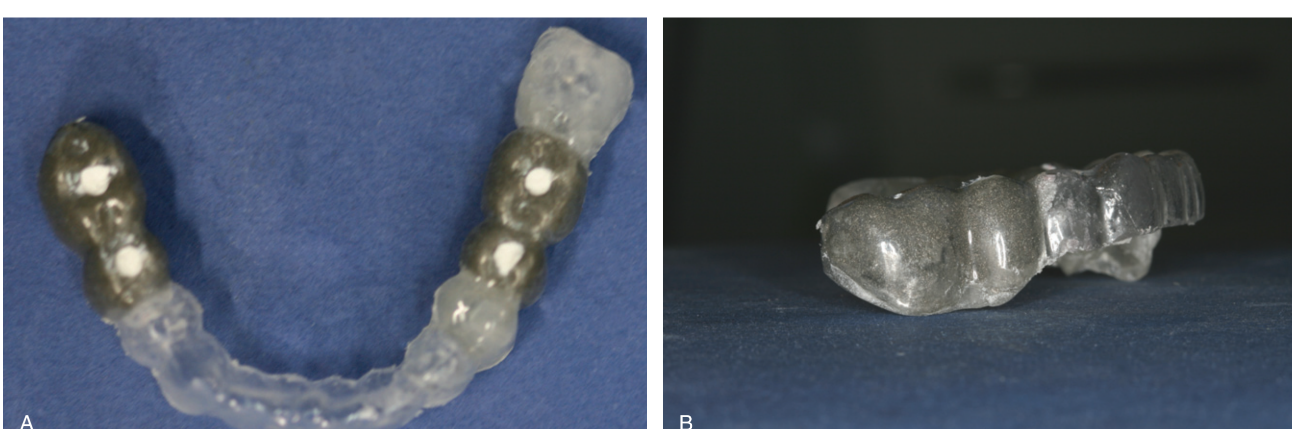

FIGURE 2. A and B, Radiographic template with radiopaque material (amalgam powder) to indicate the outline of the planned restoration and gutta-percha for the implant axis on the CBCT.

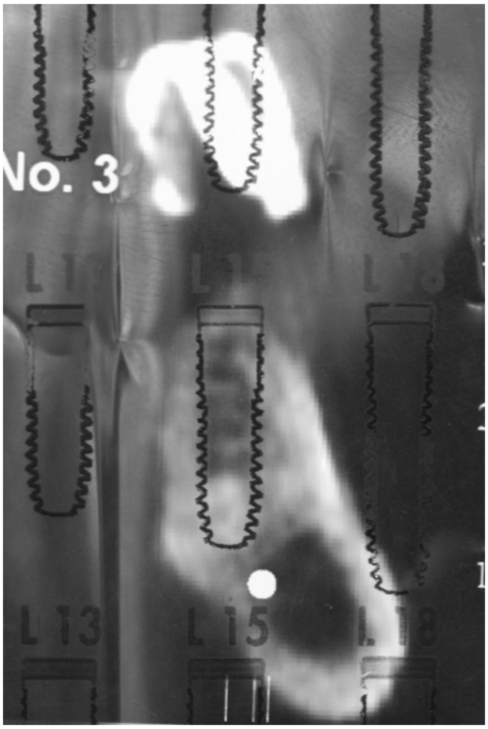

FIGURE 3. Cross-sectional image of the left mandibular second premolar region (#20) at the first reconstruction. A 4 × 15-mm implant was initially selected.

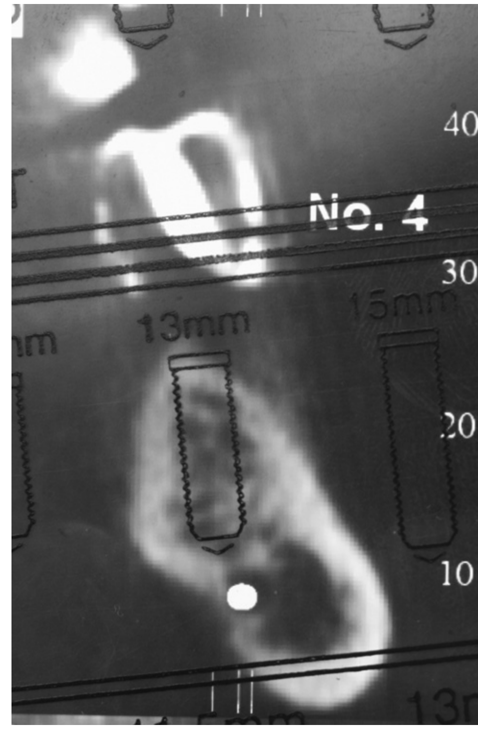

FIGURE 4. Cross-sectional image of the left mandibular first molar region (#19) at the first reconstruction. A 4 × 13-mm implant was initially selected.

premolar (#20) a 4 × 15-mm implant (Figure 3) and for the left first molar (#19) a 4 × 13-mm implant were initially selected (Figure 4).

On the CBCT, it was observed that the transverse orientation lines—that are drawn before 3D reconstruction and serve as a frame for the cross-sectional images—were aligned parallel to the inferior border of the mandible and not parallel to the occlusal plane, as dictated from the radiographic guide (Figure 5). For this reason, a new digital reconstruction of the existing CBCT was decided upon to avoid exposing the patient to additional radiation. The base orientation line in the new reconstruction was parallel to the occlusal plane, and new cross-sectional images were obtained. Consequently, the inclination of the transverse images was altered compared with the previous reconstruction. The different orientation lines in the two reconstructions of the same CBCT can be clearly observed on Figure 6.

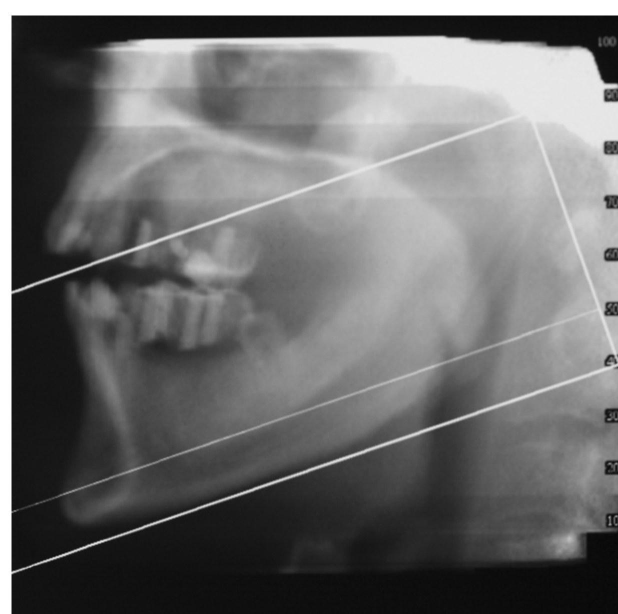

FIGURE 5. The transverse orientation lines were drawn parallel to the inferior border of the mandible and not parallel to the occlusal plane.

 DOI 10.1111/j.1708-8240.2012.00505.x

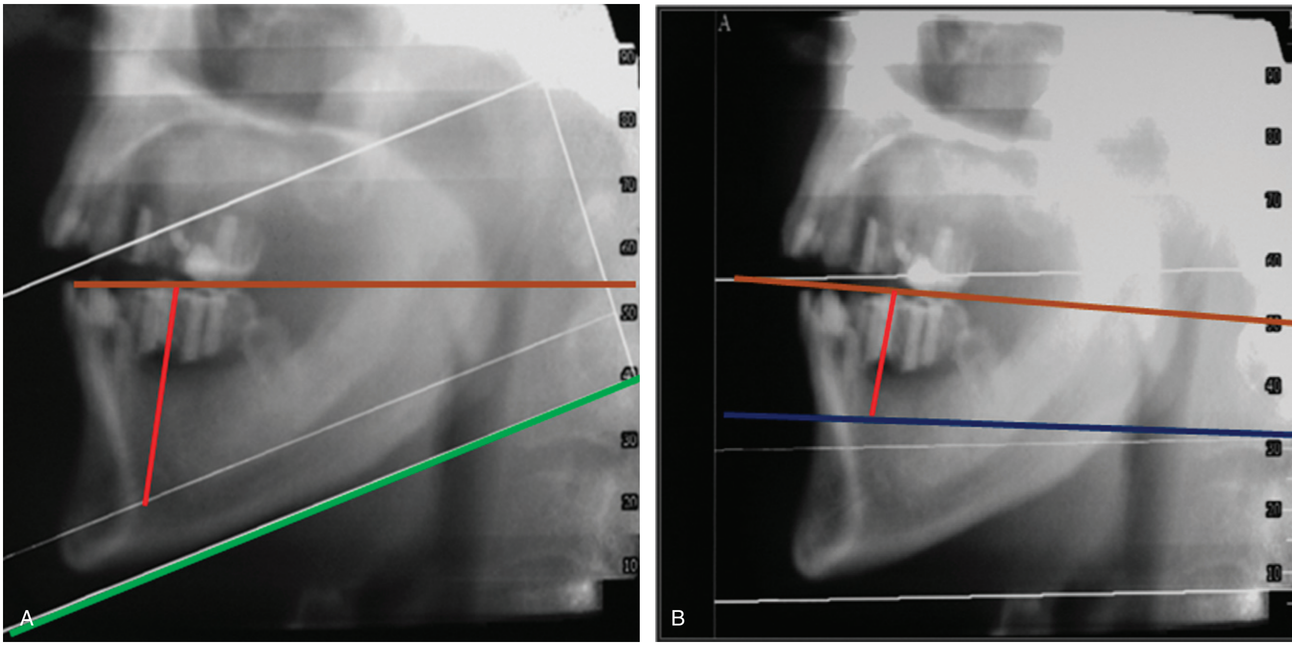

FIGURE 6. Orientation lines on the two reconstructions: A, the first reconstruction and B, the second reconstruction. Red indicates the axis of the implant and the restoration, orange indicates the occlusal plane as dictated by the radiographic template, green indicates the inferior border of the mandible, blue indicates an orientation line parallel to the occlusal plane.

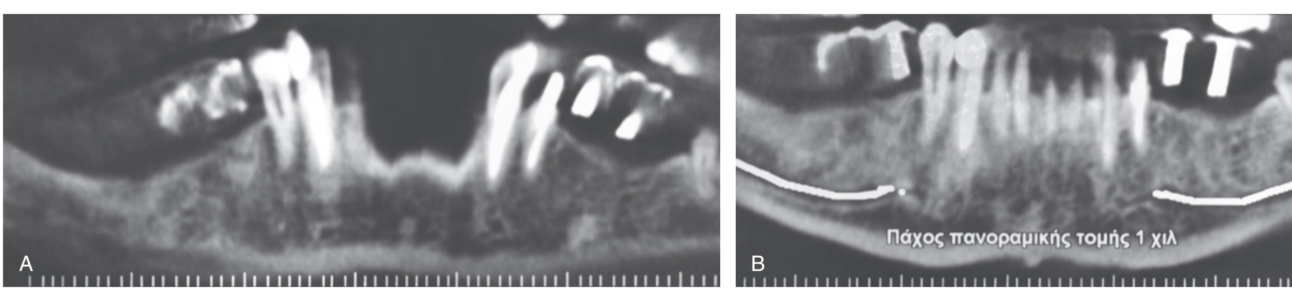

FIGURE 7. Panoramic views of the two reconstructions: A, the first and B, the second. The second image shows less distortion.

Focusing on the definition of the occlusal plane, one of two options can be applied: the occlusal plane can be recognized either by the teeth (if existing) or alternatively by the occlusal surfaces, as represented from the template. In the described case, the occlusal plane as defined by the maxillary teeth was selected. As an option, the mandibular teeth on the template could have also been used as reference points (Figure 6).

In Figure 7, the panoramic views of the two separate reconstructions are shown. Inclination of the gutta-percha markers toward the long axis of the existing premolars was significantly influenced by the alignment of the scanning level. In the second reconstruction, the gutta-percha markers appeared parallel to the premolars, as they were placed during laboratory fabrication. The secondary reconstruction was obviously closer to the clinical situation.

When comparing the cross-sectional images from the two reconstructions, different morphology of the left side of the mandible was also observed. The inclination of the alveolar crest to the sagittal plane (labial–lingual) appeared different. Both the second premolar

 DOI 10.1111/j.1708-8240.2012.00505.x

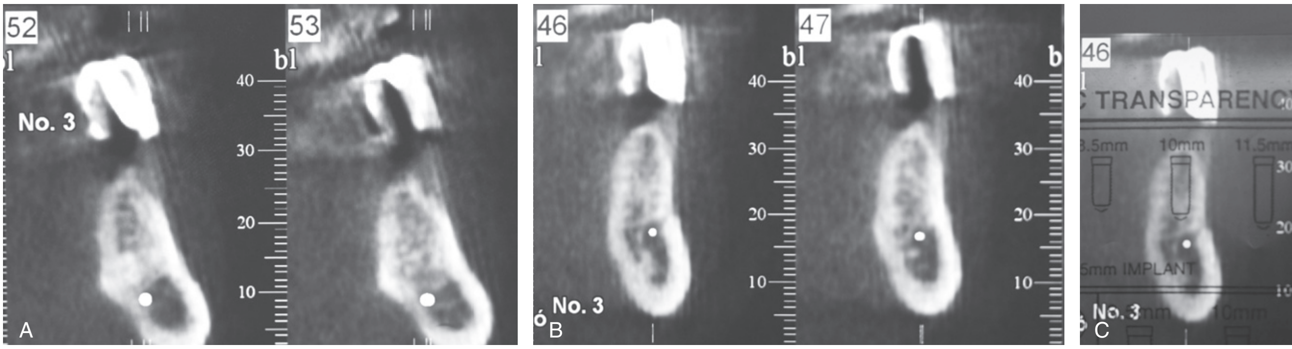

FIGURE 8. Cross-sectional images of the mandibular second premolar region (#20): A, is the first reconstruction and B, the second one. The difference in the morphology of the alveolar ridge is obvious. C, A 3.25 × 10-mm implant was finally selected for the second premolar region (#20) according to the second reconstruction.

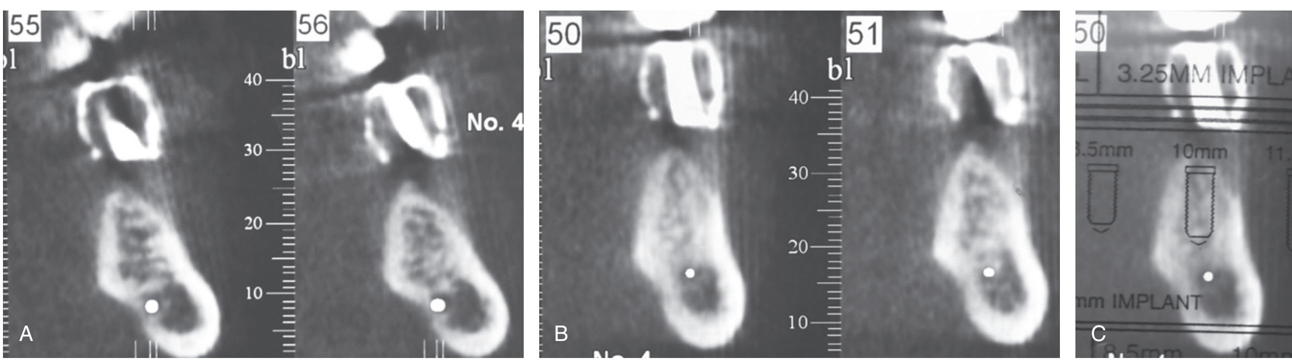

FIGURE 9. Cross-sectional images of the mandibular first molar region (#19): A, is the first reconstruction and B, the second one. The difference in the morphology of the alveolar ridge is obvious. C, A 4 × 10-mm implant was finally selected for the first molar region (#19) according to the second reconstruction.

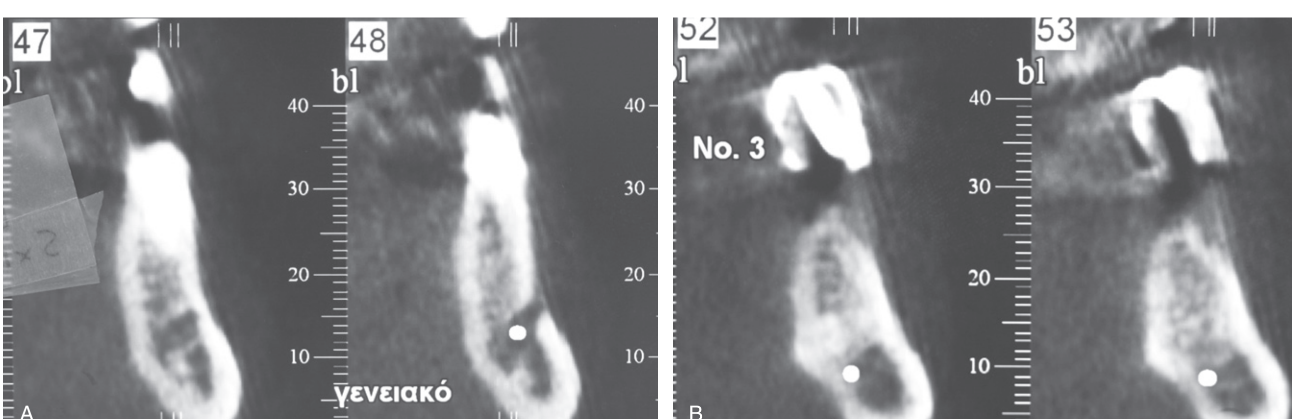

FIGURE 10. A, At the first reconstruction, the mental foramen appeared at cross-section #48. B, At the same (first) reconstruction, the crown of the second premolar (area #20)—as depicted by the template—was observed after four cross-sections (#52) indicating 8-mm distance.

 DOI 10.1111/j.1708-8240.2012.00505.x

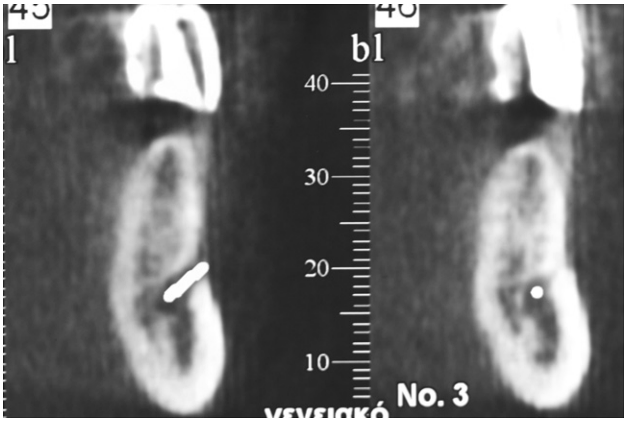

FIGURE 11. At the second reconstruction, the mental foramen appeared underneath crown of the second premolar, as depicted from the template.

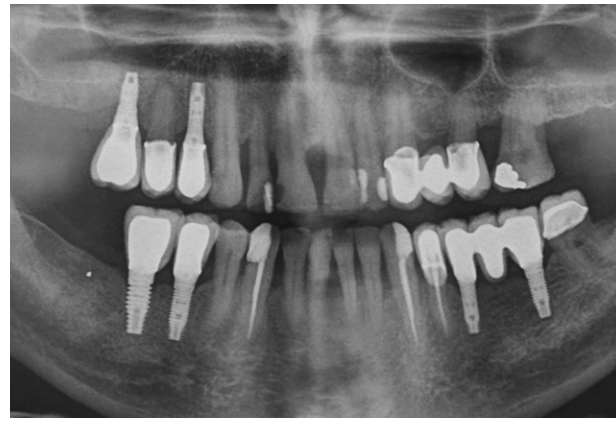

FIGURE 12. Radiographic examination at the annual recall.

(Figures 8A and 8B) and first molar region (Figures 9A and 9B) appeared significantly different in the cross-sectional images. According to the second reconstruction, a 3.25×10-mm implant (Figure 8C) for the second premolar and a 4×10-mm implant (Figure 9C) for the first molar region were selected.

The distance between the mental foramen and the crown of the second premolar (#20)—as indicated by the radiopaque material on the template—appeared different in the cross-sectional images in the two reconstructions, as shown in Figures 10 and 11. In the first reconstruction, the second premolar crown (#20), as depicted in the template, appeared in cross-sectional image #48 (Figure 10A). The mental foramen was observed in cross-sectional image #52 (four tranverse views away), indicating 8-mm horizontal distance (Figure 10B). In the second reconstruction (Figure 11), the mental foramen appeared situated just underneath the second premolar area on the same cross-sectional image (#45).

According to presurgical planning based on the second reconstruction of the CBCT, the implants were placed in the selected areas by the use of the surgical template. After uneventful osseointegration, the prosthetic restoration was completed, and the implants showed no signs of complications or infection at the annual recall (Figure 12).

Case B

The inclination of the scanning level as related to the occlusal plane of the patient and its importance on the accuracy of CBCT could also be clearly observed in a second case. A 30-year-old white female patient was referred for restoration of the missing mandibular left first molar (#20). After clinical examination and panoramic radiography, an implant and implant crown were planned, as opposed to a three-unit fixed partial denture, to avoid preparation of the adjunct teeth and removal of structures from those teeth.

The patient was referred for CBCT imaging. In this case, a piece of amalgam was remaining at the crest of the alveolar ridge after the tooth extraction. This piece of amalgam was not removed before CBCT, as it could serve as a reference point on the cross-sectional images. As the edentulous space was limited to a single tooth, the use of a radiographic template in this case was not considered to be mandatory (Figure 13), however, some clinicians might prefer it given certain clinical criteria.

The initial reconstruction of the CBCT was performed with the orientation line parallel to the inferior border of the mandible (Figure 14). At the corresponding cross-sectional images of the first molar region, the alveolar ridge appeared as ellipse-shaped, and a

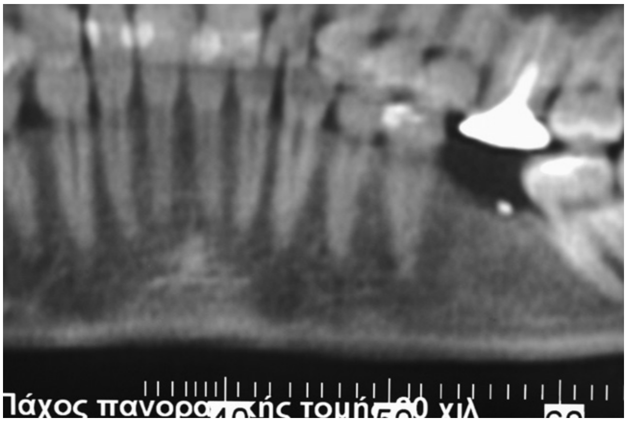

FIGURE 13. Case B: panoramic view of the CBCT.

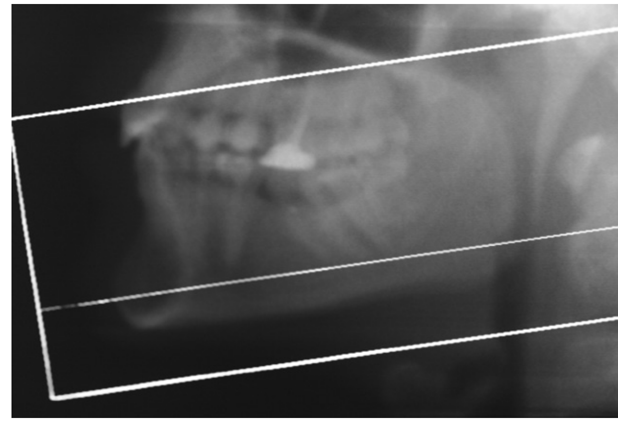

FIGURE 14. First reconstruction with the scanning level parallel to the inferior border of the mandible.

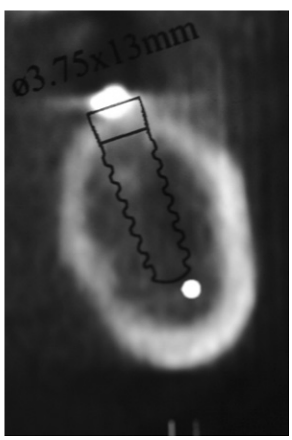

FIGURE 15. Cross-sectional image of the mandibular first molar region at the first reconstruction. The mandible appears elliptical in shape and a 3.75 × 13-mm implant could be initially selected.

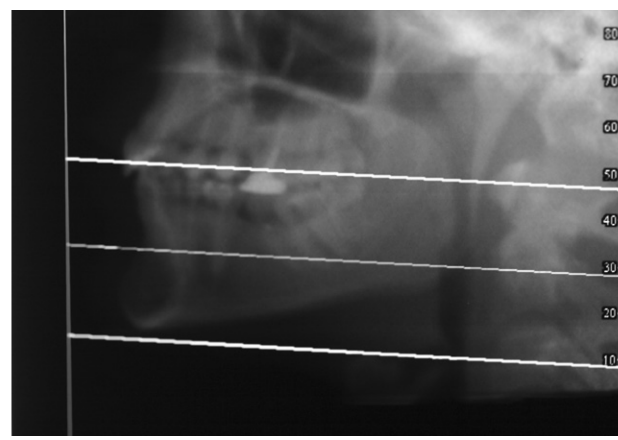

FIGURE 16. Second reconstruction with the scanning level parallel to the occlusal plane of the mandibular teeth.

3.75 × 13-mm implant was overlaid in the image (Figure 15).

From the same CBCT, a second reconstruction was performed, with the orientation line parallel to the occlusal plane of the patient (Figure 16). On the cross-sectional images of the second reconstruction, the alveolar ridge appeared more cylindrical in shape, and a shorter (3.75 × 11.5 mm) implant was selected (Figure 17). The second reconstruction was closer to the clinical anatomy as the cross-sectional images were perpendicular to the alveolar ridge, resulting in reduced distortion.

If the surgical planning had been accomplished based on the first reconstruction and a 13-mm-long implant had been used, damage to the inferior mandibular nerve may likely have occurred. The differences in the depicted shape of the mandible in the cross-sectional images are explained in the Discussion section.

DISCUSSION

CBCT imaging for presurgical evaluation of the bone substrate prior to implant placement is frequently used

 DOI 10.1111/j.1708-8240.2012.00505.x

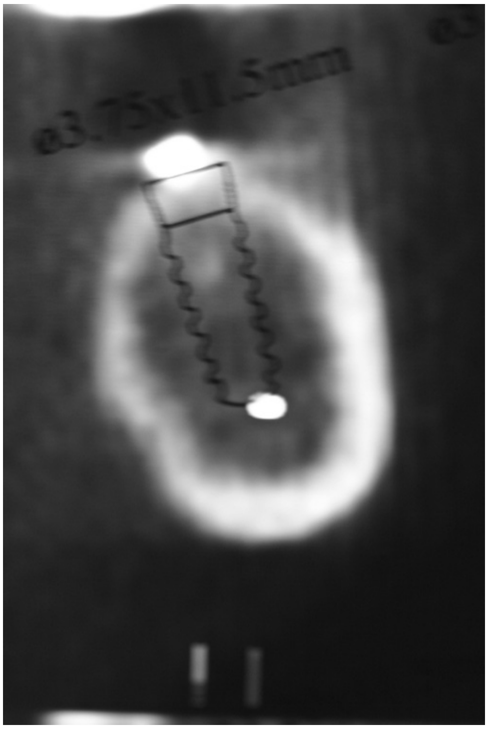

FIGURE 17. Cross-sectional image of the mandibular first molar region (#19) at the second reconstruction. The mandible appears more cylindrical, and a 3.75 × 11.5-mm implant was finally selected.

as it allows precise measurements of the alveolar crest.[19–21] Proper patient positioning is desirable to insure accurate CBCT with minimum distortion[22–24] and optimal image quality.

Ideally, the CBCT planning should be performed perpendicular to the long axis of the previously existing tooth and the planned implant.[18,25] If the mandible is not properly aligned during CBCT or image reconstruction, distorted cross-sectional images may result. The angle created from the inferior border of the mandible to the level of scanning (orientation line) is usually called "gantry angle."[26–28]

Choi and colleagues[26] investigated the influence of the gantry angle on a dry human mandible using a resin block model at 0, 15, and 30 degrees. Increasing the gantry angle resulted in obvious distortion on the reformatted cross-sectional images.

Kim and colleagues[27] in a study of dry human skulls investigated the influence of the mandible angulation to the accuracy of depicted dimensions on cross-sectional images of CT scans. In the results of this study, no significant error was found in the areas of mandibular premolars, but more intense deviations in the molar areas. The authors suggested the use of the occlusal plane as indicated from an accurate radiographic guide as orientation line.

Sforza and colleagues[28] in an in vitro study of a dry human skull examined the effect of positioning of the mandible on the accuracy of the cross-sectional images of reformatted CT dental scans. Additionally, they used a specific software (DentalVox software, 2GO.com, Columbus, OH, USA) to evaluate the possible compensation of the reformatted images of the CT scans. More specifically, they compared cross-sectional images obtained from CT scans with inclinations up to 30 degrees from the horizontal level as represented by the inferior border of the mandible in the experimental setup. The results showed deviations from the existing situation ranging from 2 to 51% in linear measurements. The use of the specific software could partially compensate for the distortion created by improper position of the mandible.

Cucchiareli and colleagues[29] in an in vitro study of 15 edentulous human skulls measured the differences in CT dental scans using the horizontal plane and the prosthetic occlusal plane (Camper prosthetic plane) as orientation lines. The authors found that using the horizontal plane showed significantly increased magnification compared with the reconstruction based on the Camper prosthetic plane which was represented by a base plate.

Chan and colleagues[30] in a recent systematic review examined most parameters related to the accuracy of CT dental scans. Although most factors were extensively discussed, the need for proper alignment of the scanning levels was not underlined. On the other hand, most commercially available computer aided design-computer aided manufacturing (CAD-CAM) navigation software systems recommend accurate definition of the orientation lines before image reconstruction without explaining its need.

 DOI 10.1111/j.1708-8240.2012.00505.x

In both presented cases, the CBCT reconstructions that were performed using the inferior border of the mandible as orientation line resulted in distorted cross-sectional images. A second reconstruction of the existing CBCT, using the occlusal plane of the patient as an orientation line, produced cross-sectional images that depicted the bone substrate more accurately. A possible explanation for this finding may be the angle at which the cross-sectional images are produced. If the posterior areas of the mandible are considered as a cylinder that is cut perpendicular to its long axis, the cross-sectional images appear as a circle with a certain diameter. These images are closer to the clinical situation and to the surgical anatomy. If the cylinder is "cut" to an angle declining from the perpendicular line, the phenomenal cross-sectional is depicted as an ellipse with greater phenomenal diameter (Figure 18).

The bone drilling for implant placement is most frequently performed perpendicular to the peak of the alveolar crest, along the axis of the tooth in the planned restoration. Variation in declination from the planned axis may lead to improper implant placement. The distance from the adjacent teeth and the mental foramen may also be affected. For these reasons, it is essential to use an accurate radiographic template indicating the occlusal plane of the patient. Following the occlusal plane as an orientation line offers more accurate cross-sectional images that represent the existing anatomy of the specific region. The radiopaque markers on the template allow precise recognition of each surgical site and also indicate the planned implant axis. Any deviation during 3D reconstruction of the CBCT can and should be recognized prior to definite surgical planning. Eventually, a second reconstruction may produce cross-sectional images of greater accuracy without exposing the patient to additional radiation.

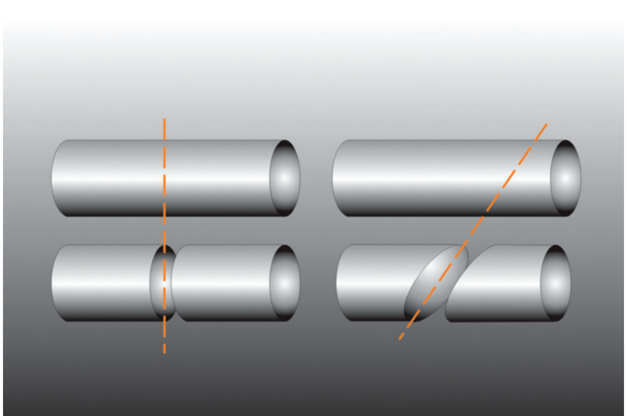

FIGURE 18. Diagrammatic cross-sections of a cylinder perpendicular to its long axis (left) and with side inclination (right).

The occlusal plane cannot always be recognized in partially or especially completely edentulous patients without the use of an accurate radiographic guide (template). The radiographic guide should depict the outer surface of the planned restoration, in order to facilitate its recognition on the CBCT images. If only gutta-percha is used to indicate the long axis of the implants, the contour of the restoration is not shown on the CBCT and proper image reconstruction as well as implant positioning may be more challenging.

The use of a radiographic template during CBCT facilitates the orientation of the scanning level and the recognition of the exact areas of concern at the cross-sectional images. The radiographic template that has been used in the earlier-described case offers two significant advantages. The long axis of the implant is indicated from gutta-percha, and the contour of the planned restoration is depicted from amalgam powder. It is also an easy and low-cost technique requiring no additional equipment. Compared with other radiopaque materials such as barium sulfate or zinc foil, amalgam powder offers a sharper image with minimum thickness. Additionally, the fabricated template can be transformed to a surgical template in a very short time by removing the amalgam powder and the gutta-percha points with diluting agents such as acetone and chloroform.

Both radiographic case studies were possible due to use of CBCT technology. Cone-beam software allows proper orientation of the gathered digital data and proper alignment of the scanning level. Conventional CT dental scan software does not always offer that feature, making proper interpretation unpredictable. The CBCT provides improved imaging and offers valuable information for the treatment planning.[31] The interpretation of the CBCT images, with its possibilities

 DOI 10.1111/j.1708-8240.2012.00505.x

and limitations, is very important for presurgical implant evaluation. A clinician using this technology should have proper training. If not, an experienced dental radiologist may offer significant assistance. A second reconstruction without exposing the patient to additional radiation is always indicated when proper occlusal plane orientation has not been performed.

CONCLUSION

Within the limitations of this preliminary clinical report, it is recommended that the initial images of the CBCT should be scanned parallel to the planned occlusal plane of the patient. The radiographic template offers valuable information not only about the correct occlusal plane but also about the location and inclination of the implant and the restoration. Proper reconstruction of the CBCT results in more accurate cross-sectional images and may contribute significantly to better presurgical implant and reconstruction planning.

DISCLOSURE AND ACKNOWLEDGEMENTS

The authors do not have any financial interest in the companies whose products are included in this article.

The authors thank sincerely Prof. Dr. K. Tsichlakis, Head of the Department of Oral Diagnosis, Oral and Maxillofacial Radiology, University of Athens, Greece for his valued remarks in the preparation of this paper and the staff of the Department of Computerized Tomography for their support in performing the CBCT scans.

REFERENCES

1. Backstrom A, Welander U, McDavid WD, et al. The effect of parameters on resolution in rotational panoramic radiography. A mathematical analysis. Dentomaxillofac Radiol 1989;18:169–76.
2. Eckerdal O, Kvint S. Presurgical planning for osseointegrated implants in the maxilla: a tomographic evaluation of available alveolar bone and morphological relations in the maxilla. Int J Oral Maxillofac Surg 1986;15:722–6.
3. Rothman SLG, Chaftez N, Rhodes ML, Schwartz MS. CT in the preoperative assessment of the mandible and maxilla for endosseous implant surgery. Radiology 1988;168:171–5.
4. Schwarz MS, Rothman SLG, Rhodes ML, Chafetz N. Computed tomography. I. Preoperative assessment of the mandible for endosseous implant surgery. Int J Oral Maxillofac Implants 1987;2:137–41.
5. Schwarz MS, Rothman SLG, Rhodes ML, Chafetz N. Computed tomography. II. Preoperative assessment of the maxilla for endosseous implant surgery. Int J Oral Maxillofac Implants 1987;2:143–8.
6. Garber DA. The esthetic dental implant: letting restoration be the guide. J Oral Implantol 1996;22: 45–50.
7. Gaber DA, Belser UC. Restoration-driven implant placement with restoration-generated site development. Compend Contin Educ Dent 1995;16:798–802.
8. Annibali S, La Monaca G, Tantardini M, Cristalli MP. The role of the template in prosthetically guided implantology. J Prosthodont 2009;18:177–83.
9. Becker CM, Kaiser DA. Surgical guide for dental implant placement. J Prosthet Dent 2000;83:248–51.
10. Akca K, Iplikcioglu H, Cehreli MC. A surgical guide for accurate mesio-distal paralleling of implants in the posterior edentulous mandible. J Prosthet Dent 2002;87:233–5.
11. Lal K, White GS, Morea DN, Wright RF. Use of stereolithographic templates for surgical and prosthodontic implant planning and placement. Part I. The concept. J Prosthodont 2006;15:51–8.
12. Burns DR, Crabtree DG, Bell DH. Template for positioning and angulation of intraosseous implants. J Prosthet Dent 1988;60:479–83.
13. Ku YC, Shen YF. Fabrication of a radiographic and surgical stent for implants with a vacuum former. J Prosthet Dent 2000;83:252–3.
14. Arfai NK, Kiat-amnuay S. Radiographic and surgical guide for placement of multiple implants. J Prosthet Dent 2007;97:310–2.
15. Kopp KC, Koslow AH, Abdo OS. Predictable implant placement with a diagnostic/surgical template and advanced radiographic imaging. J Prosthet Dent 2003;89:611–5.
16. Basten CH, Kois JC. The use of barium sulfate for implant templates. J Prosthet Dent 1996;76:451–4.
17. Abrahams J. Dental CT imaging: a look at the jaw. Radiology 2001;219(2):334–45.
18. Angelopoulos C. Cone beam tomographic imaging anatomy of the maxillofacial region. Dent Clin North Am 2008;52:731–52.

 DOI 10.1111/j.1708-8240.2012.00505.x

19. Clark DE, Danforth RA, Barnes RW, Burtch ML. Radiation absorbed from dental implant radiography and comparison of linear tomography CT scan and panoramic and intra oral techniques. J Oral Implantol 1990;16:156–64.
20. Gher ME, Richardson AC. The accuracy of dental radiographic techniques used for evaluation of implant fixture placement. Int J Periodontics Restorative Dent 1995;15:268–83.
21. Higginbottom FL, Wilson TG. Three dimensional templates for placement of root-form dental implants; a technical note. Int J Oral Maxillofac Implants 1996;11:787–93.
22. Lindh C, Peterson A. Radiological examination for the location of the mandibular canal: a comparison between panoramic radiography and conventional tomography. Int J Oral Maxillofac Implants 1989;4:249–53.
23. Kohavi D, Bar-Ziv J, Marmary Y. Effect of axial plane deviation in reformatted computer tomography of the mandible. Dentomaxillofac Radiol 1997;26:327–31.
24. Kim KD, Park CS. Effect of variable scanning protocols on the pre-implant site evaluation of the mandible in reformatted CT. Korean J Oral Maxillofac Radiol 1999;29:21–32.
25. Ames JR, Johnson RP, Stevens EA. Computerized tomography in oral and maxillofacial surgery. J Oral Surg 1980;38:145–9.
26. Choi SC, Ann CH, Choi HM, et al. Accuracy of reformatted CT image for measuring the pre-implant site: analysis of the image distortion related to the gantry angle change. Dentomaxillofac Radiol 2002;31: 273–7.
27. Kim KD, Jeong HO, Choi SH, et al. Effect of mandibular positioning on pre-implant site measurements of the mandible in reformatted CT. Int J Periodontics Restorative Dent 2003;23:177–83.
28. Sforza NM, Franchini FF, Lamma A, et al. Accuracy of computerized tomography for the evaluation of mandibular sites prior to implant placement. Int J Periodontics Restorative Dent 2007;27:589–95.
29. Cucchiareli D, Kitrilakis A, Pastori E. Tomographic distortions in toothless patients. Acta Odontol Latinoam 2008;21:35–41.
30. Chan HL, Mish K, Wang HL. Dental imaging in implant treatment planning. Implant Dent 2010;19:288–98.
31. Koong B. Cone beam imaging: is this the ultimate imaging modality? Clin Oral Implants Res 2010;21:1201–8.

Reprint requests: Stefanos Kourtis, Assistant Professor, Dept. of Prosthodontics, University of Athens, Greece, Plaza Chrys. Smyrnis 14 17121, Athens, Greece; email: stefkour@dent.uoa.gr

This article is accompanied by commentary, Presurgical Planning in Implant Restorations: Correct Interpretation of Cone-Beam Computed Tomography for Improved Imaging, Jeff Thomas, DDS
DOI 10.1111/j.1708-8240.2012.00506.x