Nerve Damage Assessment Following Implant Placement in Human Cadaver Jaws: An Ex Vivo Comparative Study

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The present study compared the use of cone beam computerized tomography (CBCT) images and intra-oral radiographs in the placement of final implant drills in terms of nerve damage to cadaver mandibles. Twelve cadaver hemimandibles obtained from 6 cadavers were used. Right hemimandibles were imaged using peri-apical radiography and left hemimandibles using CBCT, and the images obtained were used in treatment planning for the placement of implant drills (22 for each modality, for a total of 44 final drills). Specimens were dissected, and the distances between the apex of the final implant drill and the inferior alveolar neurovascular bundle and incisive nerve were measured using a digital calliper. Nerves were assessed as damaged or not damaged, and the Chi-square test was used to compare nerve damage between modalities ($P < 0.05$). Nerve damage occurred with 7 final drills placed based on peri-apical radiography (31.8%) and 1 final drill placed using CBCT images (4.5%). The difference in nerve damage between imaging modalities was statistically significant ($P = 0.023$), with CBCT outperforming intraoral film in the placement of final implant drills ex vivo. In order to prevent nerve damage, CBCT is recommended as the principal imaging modality for pre-implant assessment.

Key Words: inferior alveolar nerve, incisive nerve, dental implant, CBCT, radiography, nerve damage

INTRODUCTION

Presurgical implant planning is of paramount importance for the successful outcome of dental implant treatment. In order to ensure implants are appropriately placed, planning should include the identification of critical anatomical landmarks and a bone-quality assessment in addition to prosthetic considerations. An inappropriate depth or insertion path is a common occurrence during the insertion of implant fixtures and can result in sensory disturbances[1–3] due to direct damage or stretching of the inferior alveolar nerve if a fixture placed anterior to the mental foramen engages the inferior alveolar nerve in the incisive branch of the mandibular canal or the incisive canal.[3,4] This can result in a loss of lip and chin sensation and lead to lip biting, impaired speech and diminished salivary retention that will have significant impact on a patient's daily life.[1] In order to prevent this type of damage, adequate information is needed regarding jaw bone quality and quantity in the implant region.[5,6] In addition, anatomical knowledge regarding the location of mandibular canal, the course of inferior alveolar nerve and incisive nerve is essential.[1]

Radiography combined with clinical examination is the only method available for the presurgical evaluation of implant sites in routine dental practice; however, while easily accessible, peri-apical and panoramic radiographs can provide only

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DOI: 10.1563/AAID-JOI-D-11-00191

two-dimensional (2D) information on teeth and bone.[5,6] The popularity of cone-beam computerized tomography (CBCT) in implant planning has increased in recent years, but its use prior to dental implant surgery is still not as common as it should be. In comparison to traditional medical CT systems, dental CBCT units offer reduced effective radiation doses, shorter acquisition scan times, easier imaging and lower costs. Rather than the fan-shaped X-ray beam emitted by conventional CT technology, CBCT units emit a cone-shaped beam that covers the entire region of interest, allowing images to be acquired in only one pass or less around the patient's head. The beam remnant is captured on a 2D planar detector,[7,8] and the data obtained can be processed using commercially available implant simulation software to provide a pre-operative view of anatomical structures in the jaw.[9]

Unfortunately, it is not possible to obtain accurate postsurgical measurements of the distance between implants and nerve structures in routine clinical practice. Therefore, the aim of the present study was to compare the occurrence of nerve damage due to the placement of final implant drills based on anatomical information provided by CBCT and radiographic images ex vivo. The anatomical findings may provide useful in preventing nerve injuries due to dental implant surgery in the mandible.

Materials and Methods

The study sample comprised 12 cadaver hemimandibles obtained from 6 individuals who gave prior informed consent for their use in medical research. All specimens were stored in 10% neutral formalin prior to use. Right hemimandible sections were imaged using peri-apical radiographs, and the radiographic images were measured using a digital calliper during treatment planning, whereas left hemimandible sections were imaged using CBCT, and treatment was planned using the measurements obtained from cross-sectional views provided by built-in measurement tools. For both imaging modalities, exposure parameters were determined based on pilot studies conducted to ensure optimal image quality with good visibility of the trabecular pattern.

For the intra-oral radiographs, Kodak Insight Film (Size 2, E/F sensitivity; Eastman Kodak Co, Rochester, NY) was exposed for 0.3 s using an Evaluation X 3000-2C X-ray unit (New Life Radiology Srl, Grugliasco, Turin, Italy) operated at 70 kVp and 8 mA with a focus-receptor distance of 20 cm and automatically processed on the same day using an Extra-x Velopex (Medivance Instruments Ltd, London, England) and fresh chemicals (Hacettepe, Ankara, Turkey) in accordance with the manufacturer's instructions (Figure 1a and b). CBCT images were acquired using a Veraviewepocs 3D model X550 (J Morita Mfg. Corp, Kyoto, Japan) at 60–90 kV, 3 mA and an exposure time of 9.4 s, with a 40×40 mm FOV (0.125 mm^3 voxel size; Figure 2).

Following mucosal flap elevation, implant drills (MIS, Implants Technologies Ltd, Shlomi, Israel) were placed in accordance with treatment plans designed to provide a safety zone of 1–2 mm from all critical structures (mandibular canal, mental foramen, and incisive foramen). In each hemimandible section, 3–4 final implant drills were placed, making a total of 22 final implant drills per imaging modality (13 in the posterior region and 9 in the anterior foraminal region). All implants were inserted by 1 experienced clinician in implant surgery. Planned implant lengths for both modalities are shown in Table 1.

In order to measure actual distances between implants and anatomical structures, following implant drill placement, buccal cortical and spongy bone surrounding the mental foramen and inferior alveolar canal was removed using a round steel bur and a sharp spoon. A digital caliper that is accurate to 0.01 mm (Ningbo Everest Imp & Exp Co, Zhejiang, China) was used to measure the following distances (according to the location of the final implant drill):

- IN: distance between incisive nerve and drill apex
- IAN: distance between inferior alveolar nerve and drill apex
- INB: distance between incisive nerve branch and drill apex.

In addition, the thin branches of the incisive nerve (TBIN) and the thin branches of the inferior alveolar nerve (TBIAN) were assessed and recorded as damaged or not damaged (Figures 3 and 4). Nerve damage after final implant drill placement using intraoral radiography and CBCT was compared using the χ^2 test, with the level of significance set at $P < 0.05$.

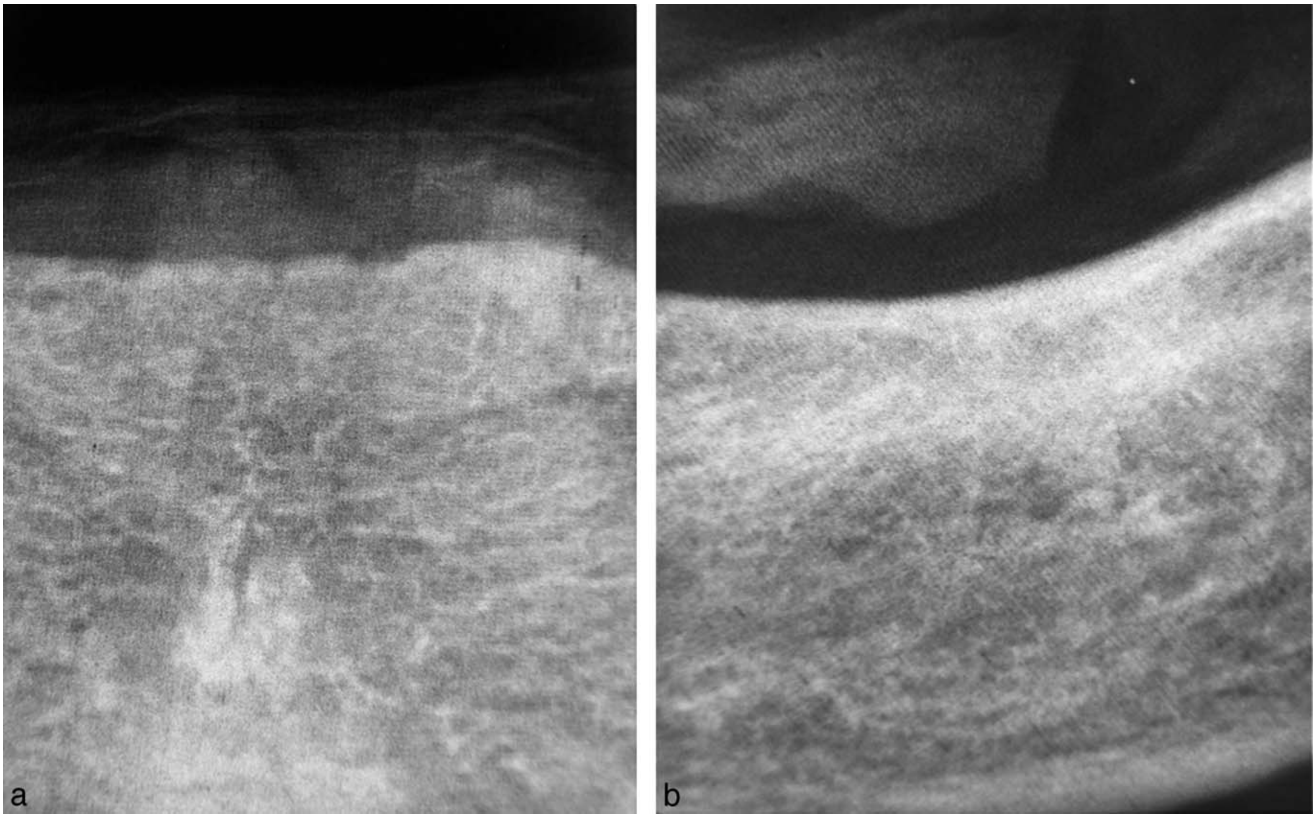

Figure 1. (a) Intra-oral peri-apical radiography of the anterior foraminal region of an edentulous cadaver mandible section before implant placement. (b) Intra-oral peri-apical radiography of the premolar region of an edentulous cadaver mandible section before implant placement.

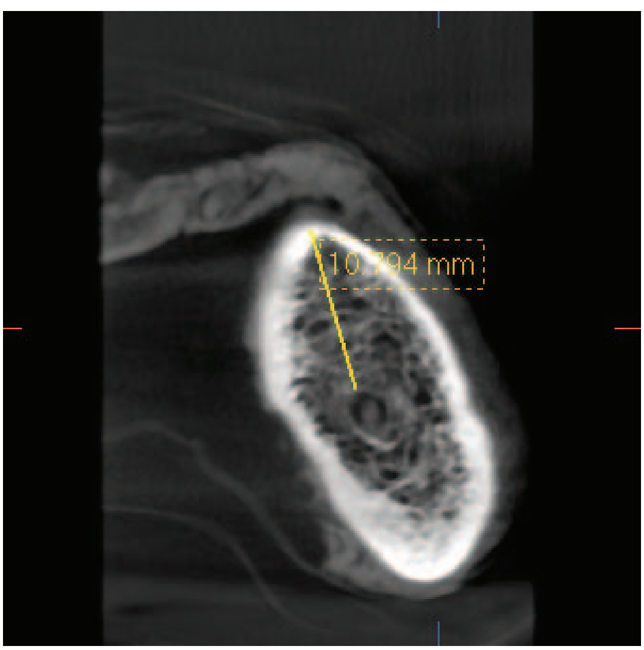

Figure 2. Cross-sectional cone beam computerized tomography image of an edentulous cadaver mandible section and available bone measurement obtained by built-in measurement tool.

Results

Actual distances (mm) between implant apices and adjacent nerve structures and actual nerve damage from implant drills placed using peri-apical radiographic treatment planning are given in Table 2. A total of 7 out of 22 final drills (31.8%) caused nerve damage. In the posterior region, 3 of 13 final implant drills (23.8%) caused inferior alveolar nerve damage (1 in the main branch of the IAN and 2 in the thin branches of the IAN). Of the remaining 10 final implant drills (76.2%), the distance between the drill apex and the IAN ranged from 0.41 mm to 2.22 mm. In the region anterior to the mental foramen, 4 of 9 final implant drills (44.4%) caused incisive nerve damage (2 in the main branch of the IN and 2 in the thin branches of the IN). Of the remaining 5 final implant drills (55.6%), the distance between the drill apex and the IAN ranged from 0.47 mm to 2.67 mm.

Actual distances (mm) between implant apices and adjacent nerve structures and actual nerve damage from implant drills placed using CBCT

Table 1

Pre-planned implant lengths for both modalities

	Periapical Radiography Treatment Planning	CBCT* Treatment Planning
8 mm	7	9
10 mm	2	2
11.5 mm	6	5
13 mm	7	6

*CBCT indicates cone beam computerized tomography.

treatment planning are given in Table 3. A total of 1 out of 22 final drills (4.5%) caused nerve damage. In the posterior region, only 1 of 13 final implant drills (7.7%) caused inferior alveolar nerve damage (in the thin branches of the IAN). Of the remaining 12 final implant drills (92.3%), the distance between the drill apex and the IAN ranged from 0.11 mm to 1.71 mm. In the region anterior to the mental foramen, no nerve damage was found. The distance between the drill apex and the IAN ranged from 0.43 mm to 1.21 mm.

The difference in nerve damage between imaging modalities was found to be statistically significant ($P = 0.023$).

Discussion

An inappropriate insertion path or depth of a dental implant fixture may cause damage to the inferior alveolar nerve (IAN) or a branch of the mandibular nerve, including the inferior alveolar, mental and lingual nerves.[1,10,11] In order to prevent nerve damage, the use of three-dimensional images of the jaws in treatment planning is recommended, given the limitation of 2D imaging.[12,13] For example, one study reported distortion rates for periapical and panoramic radiographs to be 14% and 23.5%, respectively.[14]

The present study compared the use of 3D CBCT images and 2D intraoral radiographs in the placement of final implant drills in terms of nerve damage. Intraoral radiographs were used instead of panoramic radiographs because the panoramic radiographs were unable to adequately capture the hemimandibular sections in all cases. Nerve damage was observed in 7 out of 22 final drills (31.8%)—44.4% of those placed anterior to the mental foramen and 23.8 % of those placed posterior to the mental foramen—when peri-apical radiographs were used to guide implant placement. By contrast, when CBCT images were used to guide placement, nerve damage was observed in only 1 out of 22 final drills (4.5%).

In terms of limiting nerve damage due to drill placement, CBCT clearly outperformed intra-oral imaging in the assessment of implantation sites. This difference is most likely due to the greater accuracy of 3D images over 2D images. CBCT accuracy may have been facilitated by the small FOV and voxel size, and although the accuracy of intraoral radiographic images could have been improved by the use of metal calibration balls

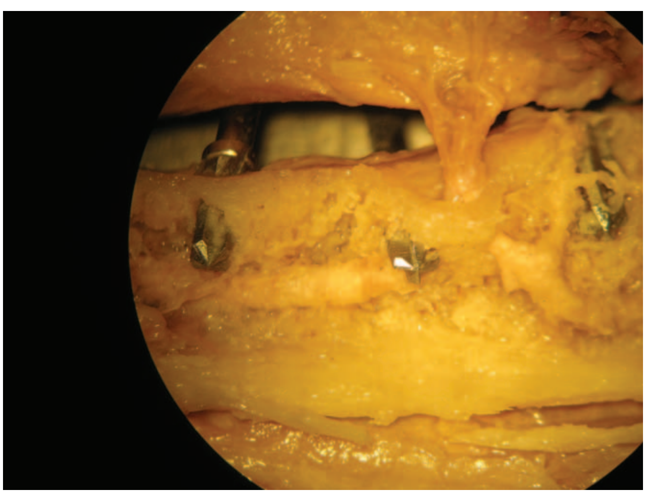

Figure 3. Damage to the inferior alveolar nerve in right mandibular section is shown by a dissection microscope Zeiss (Carl Zeiss Inc., Jena, Germany) with magnification ×4.0.

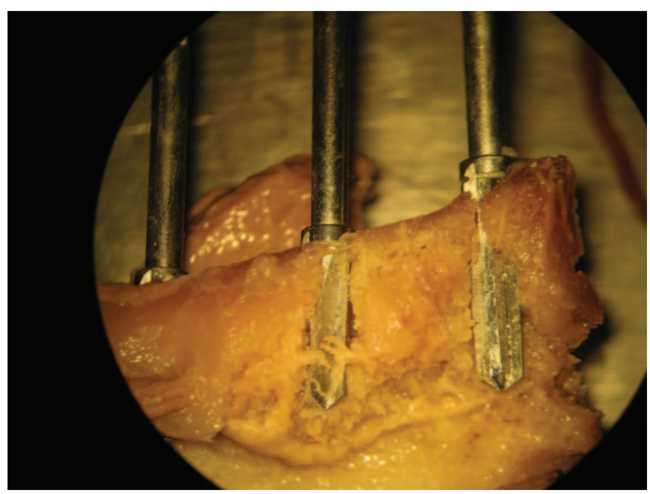

Figure 4. Damage to the thin branches of incisive nerve structures in right mandibular section is shown by a dissection microscope Zeiss (Carl Zeiss Inc., Jena, Germany) with magnification ×4.0.

Table 2

Actual distances (mm) between implant apices and adjacent nerve structures and actual nerve damage from implant drills placed using periapical radiographic treatment planning*

	Cadaver and Drill No.	Implant Length	IN	TBIN	IAN	TBIAN
1	I-1	10	0.47	-	-	-
2	I-2	13	-	-	1.34	-
3	I-3	11.5	-	-	0.75	-
4	I-4	8	-	-	1.03	-
5	II-1	13	damaged	-		-
6	II-2	13	-	-	1.07	-
7	II-3	8	-	-	0.67	-
8	III-1	13	1.34	-	-	-
9	III-2	11.5	0.96	damaged	-	-
10	III-3	11.5	-	-	damaged	-
11	III-4	8	-	-	-	damaged
12	IV-1	8	0.43	-	-	-
13	IV-2	11.5	-	-	2.22	-
14	IV-3	11.5	-	-	0.72	-
15	IV-4	10	-	-	1.11	-
16	V-1	13	-	-	0.41	-
17	V-2	13	-		0.51	-
18	V-3	8	2.67	-	-	-
19	VI-1	13	damaged	-	-	-
20	VI-2	11.5	0.98	-	-	-
21	VI-3	8	-	damaged	-	-
22	VI-4	8	-	-	-	damaged

*IN indicates closest distance between incisive nerve and implant final drill apex; IAN, closest distance between inferior alveolar nerve and implant final drill apex; INB, closest distance between incisive nerve branch and implant final drill apex; TBIN, thin branches of the incisive nerve; TBIAN, thin branches of the inferior alveolar nerve.

during imaging, calibration was not performed so as to more closely simulate actual clinical practice.

The use of cadaver specimens in this study made it possible to assess nerve damage through direct measurement following anatomical dissection; thus, our results might not have correlated with clinical complaints related to nerve damage, such as altered sensation. In fact, however, our finding of the rate of nerve damage with peri-apical radiography (31.8%) is similar to the rates of altered sensation (36%)[15] and of transient changes in sensation (34%)[16] following implant surgery reported by retrospective studies of implant patients. These findings make inferior alveolar nerve paresthesia a matter of concern as an implant complication. However, the above-mentioned studies were conducted before the commercial availability of CBCT systems. New studies that assess patient complaints following implant placement using CBCT are essential.

Longitudinal studies of oral implants placed anterior to the mental foramina in completely edentulous subjects using peri-apical radiographs to guide treatment planning suggest a very low incidence of altered sensation.[17] However, in the present study, nerve damage rates with peri-apical radiography were found to be higher (44.4%) among implant drills placed anterior to the mental foramen than among those placed in the posterior region. This may be because the use of hemi-mandibles precluded implant placement in the midincisive sites, requiring those drills placed in the anterior foramen region to be placed in an area that includes the mental nerve and a higher number of incisive branches. Of the 4 injuries, 2 occurred in the main branch of the IN and 2 in the thin branches of the IN.

In order to facilitate drilling efficiency, many implant drills are slightly longer than their corresponding implants,[18] and it is possible that the rate of nerve damage in the present study increased as a result of the use of final drills instead of implants. In this regard, it is important for the surgeon to be aware of the variations that exist in implant drill length, as nerve damage during in vivo implant

Table 3

Actual distances (mm) between implant apices and adjacent nerve structures and actual nerve damage from implant drills placed using CBCT treatment planning*

	Cadaver and drill No	Implant length	IN	TBIN	IAN	TBIAN
1	I-1	8	-	-	0.75	-
2	I-2	10	-	-	1.71	-
3	I-3	13	0.68	-	-	-
4	I-4	8	1.21	-	-	-
5	II-1	13	-	-	0.56	damaged
6	II-2	8	-	-	1.46	-
7	II-3	13	-	-	0.56	-
8	III-1	13	0.96	-	-	-
9	III-2	11.5	1.03	-	-	-
10	III-3	8	-	-	1.07	-
11	III-4	11.5	-	-	1.26	-
12	IV-1	8	0.43	-	-	-
13	IV-2	11.5	1.08	-	-	-
14	IV-3	11.5	-	-	0.72	-
15	IV-4	8	-	-	1.02	-
16	V-1	8	1.01	-	-	-
17	V-2	13	-	-	0.47	-
18	V-3	10	-	-	0.56	-
19	VI-1	13	-	-	0.11	-
20	VI-2	8	0.98	-	-	-
21	VI-3	8	0.45	-	-	-
22	VI-4	11.5	-	-	0.31	-

*CBCT indicates cone beam computerized tomography; IN, closest distance between incisive nerve and implant final drill apex; IAN, closest distance between inferior alveolar nerve and implant final drill apex; INB, closest distance between incisive nerve branch and implant final drill apex; TBIN, thin branches of the incisive nerve; TBIAN, thin branches of the inferior alveolar nerve.

placement is affected not only by radiographic planning, but by surgical procedures as well. Even with accurate measurements, low resistance of the spongy bone can cause drill slippage or over-penetration, leading to deeper or wider diameter placement that results in nerve injury.[19] In the present study, all final drills were placed after flap operation by the same operator experienced in implantology procedures. In spite of this, it is possible that the use of cadaver specimens with low bone resistance may have increased the number of nerve injuries.

In order to reduce the likelihood of injury to the neurovascular bundle, the clinician must obtain accurate measurements of the distances surrounding the mandibular canal before endosseous implants are inserted in the mandible.[19–21] However, there is limited knowledge regarding the distance between the implant and the mandibular canal that is needed to ensure nerve integrity and physiological activity although in general, a safety zone of at least 1–2 mm is recommended to avoid critical anatomical structures. In the present study, an attempt was made to establish a 1–2 mm safety zone between final drills and nerve structures in order to provide a better comparison of imaging modalities; however, the use of a small safety zone may have also increased the rate of nerve damage. In order to establish appropriate recommendations for distances between implants and anatomical structures, both biomechanical and clinical data should be evaluated.

Despite the value of CBCT in establishing accurate measurements of the distances between planned implants and the mandibular and other extra-nerve canals present in the implant site, the higher effective doses of CBCT when compared to conventional 2D imaging techniques is a matter of concern.[22,23] However, current CBCT systems that offer limited FOV and lower doses[23] may be considered safe tools for use in planning dental implants, especially in cases where only 1 to 3 implants are necessary. More importantly, in view of the results of this ex vivo study, the risk of nerve damage observed with the use of conventional radiography must not be underestimated.

Abbreviations

CBCT: cone beam computerized tomography
IAN: distance between inferior alveolar nerve and drill apex
IN: distance between incisive nerve and drill apex
INB: distance between incisive nerve branch and drill apex
TBIAN: thin branches of the inferior alveolar nerve
TBIN: thin branches of the incisive nerve

References

1. Hu KS, Yun HS, Hur MS, Kwon HJ, Abe S, Kim HJ. Branching patterns and intraosseous course of the mental nerve. *J Oral Maxillofac Surg*. 2007;65:2288–2294.
2. Kilic C, Kamburoğlu K, Ozen T, et al. The position of the mandibular canal and histologic feature of the inferior alveolar nerve. *Clin Anat*. 2010;23:34–42.
3. Uchida Y, Noguchi N, Goto M, et al. Measurement of anterior loop length for the mandibular canal and diameter of the mandibular incisive canal to avoid nerve damage when installing endosseous implants in the interforaminal region: a second attempt introducing cone beam computed tomography. *J Oral Maxillofac Surg*. 2009;67:744–750.
4. Misch CE, Crawford EA. Predictable mandibular nerve location: a clinical zone of safety. *Int J Oral Implantol*. 1990;7:37–40.
5. Schropp L, Stavropoulos A, Gotfredsen E, Wenzel A. Calibration of radiographs by a reference metal ball affects preoperative selection of implant size. *Clin Oral Investig*. 2009;13: 375–381.
6. Zitzmann NU, Margolin MD, Filippi A, Weiger R, Krastl G. Patient assessment and diagnosis in implant treatment. *Aust Dent J*. 2008;53 Suppl 1:S3–S10.
7. Kamburoğlu K, Kolsuz E, Kurt H, Kılıç C, Ozen T, Paksoy C. Accuracy of CBCT measurements of a human skull. *J Digit Imaging*. 2011;24:787–293.
8. Scarfe WC, Farman AG. What is cone-beam CT and how does it work? *Dent Clin North Am*. 2008;52:707–730.
9. Verstreken K, Van Cleynenbreugel J, Martens K, Marchal G, van Steenberghe D, Suetens P. An image-guided planning system for endosseous oral implants. *IEEE Trans Med Imaging*. 1998;17:842–852.
10. Bartling R, Freeman K, Kraut RA. The incidence of altered sensation of the mental nerve after mandibular implant placement. *J Oral Maxillofac Surg*. 1999;57:1408–1412.
11. Denio D, Torabinejad M, Bakland LK. Anatomical relationship of the mandibular canal to its surrounding structures in mature mandibles. *J Endod*. 1992;18:161–165.
12. Worthington P, Rubenstein J, Hatcher DC. The role of cone-beam computed tomography in the planning and placement of implants. *J Am Dent Assoc*. 2010;141(Suppl 3):19–24.
13. Froum S, Casanova L, Byrne S, Cho SC. Risk assessment before extraction for immediate implant placement in the posterior mandible: a computerized tomographic scan study. *J Periodontol*. 2011;82:395–402.
14. Sonick M, Abrahams J, Faiella RA. A comparison of the accuracy of periapical, panoramic, and computerized tomographic radiographs in locating the mandibular canal. *Int J Oral Maxillofac Implants*. 1994;9:455–460.
15. Ellies LG, Hawker PB. The prevalence of altered sensation associated with implant surgery. *Int J Oral Maxillofac Implants*. 1993;8:674–679.
16. Walton JN. Altered sensation associated with implants in the anterior mandible: a prospective study. *J Prosthet Dent*. 2000;83: 443–449.
17. Zarb GA, Schmitt A. The longitudinal clinical effectiveness of osseointegrated dental implants: the Toronto study. Part III: problems and complications encountered. *J Prosthet Dent*. 1990;64: 185–194.
18. Alhassani AA, AlGhamdi AS. Inferior alveolar nerve injury in implant dentistry: diagnosis, causes, prevention, and management. *J Oral Implantol*. 2010;36:401–407.
19. Juodzbalys G, Wang HL, Sabalys G. Injury of the inferior alveolar nerve during implant placement: a literature review. *J Oral Maxillofac Res*. 2011;2:e1–e20.
20. Kamburoğlu K, Kiliç C, Ozen T, Yüksel SP. Measurements of mandibular canal region obtained by cone-beam computed tomography: a cadaveric study. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2009;107:e34–e42.
21. Sammartino G, Marenzi G, Citarella R, Ciccarelli R, Wang HL. Analysis of the occlusal stress transmitted to the inferior alveolar nerve by an osseointegrated threaded fixture. *J Periodontol*. 2008; 79:1735–1744.
22. Hirsch E, Wolf U, Heinicke F, Silva MA. Dosimetry of the cone beam computed tomography Veraviewepocs 3D compared with the 3D Accuitomo in different field of views. *Dentomaxillofac Radiol*. 2008;37:268–273.
23. Garcia Silva MA, Wolf U, Heinicke F, Gründler K, Visser H, Hirsch E. Effective dosages for recording Veraviewepocs dental panoramic images: analog film, digital, and panoramic scout for CBCT. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2008;106: 571–577.