Acta Odontologica Scandinavica, 2013; 71: 1391–1398

informa
healthcare

ORIGINAL ARTICLE

Diagnostic accuracy of panoramic radiography, stereo-scanography and cone beam CT for assessment of mandibular third molars before surgery

LOUISE HAUGE MATZEN[1,2], JENNIFER CHRISTENSEN[1,2], HANNE HINTZE[1], SØREN SCHOU[2] & ANN WENZEL[1]

[1]*Section of Oral Radiology, and* [2]*Section of Oral and Maxillofacial Surgery and Oral Pathology, Department of Dentistry, Aarhus University, Denmark*

Abstract

Objective. To compare the diagnostic accuracy of panoramic imaging, stereo-scanography and cone beam computed tomography (CBCT) for assessment of mandibular third molars. ***Material and methods.*** One hundred and twelve patients (147 third molars) underwent radiographic examination by panoramic imaging, stereo-scanography and CBCT. Tooth angulation, root morphology, number of roots and relation to the mandibular canal were assessed. The same variables were assessed intra- and post-operatively and served as reference for the radiographic assessments. The diagnostic accuracy for each variable was compared between the three modalities and accuracy was further expressed as sensitivity and specificity and tested between the modalities for identifying the relation to the mandibular canal. ***Results.*** There were no significant differences between the modalities regarding tooth angulation, root morphology and number of roots. However, CBCT was more accurate than stereo-scanography for determining root bending in the bucco-lingual plane (p = 0.02). Moreover, sensitivity for direct contact to the mandibular canal (panoramic imaging: 0.29, stereo-scanography: 0.57, CBCT: 0.67) was higher for CBCT than for panoramic images (p = 0.05) and specificity for no direct contact to the mandibular canal (panoramic imaging: 0.78, stereo-scanography: 0.53, CBCT: 0.68) was higher for panoramic images and CBCT than for scanograms (p < 0.001). ***Conclusion.*** Panoramic imaging, stereo-scanography and CBCT seem equally valuable for examination of tooth angulation, number and morphology of roots of mandibular third molars. However, CBCT was more accurate for assessment of root bending in the bucco-lingual plane and more accurate than panoramic images to identify direct contact to the mandibular canal.

Key Words: *CT scanning, radiography, wisdom teeth*

Introduction

Before surgical removal of mandibular third molars, a radiographic examination is used to assess the position of the tooth, number and morphology of the roots and the relationship between the tooth and the mandibular canal. A panoramic image has been the first choice method and several studies have been conducted on accuracy of panorama radiography for assessment of mandibular third molars [1–3]. Traditionally, seven signs in the panoramic image have been used to indicate a direct contact between the roots of the third molar and the neurovascular bundle in the mandibular canal [4]. However, they seem not equally reliable. In a recent review it was concluded that three of the signs (interruption of the white line of the canal, diversion of the canal and darkening of the roots) were more valid to predict direct contact than the remaining four (deflected roots, narrowing of the root, dark and bifid root and narrowing of the canal) [5,6]. It was concluded that an absence of these signs could not ensure there was no direct contact.

Another radiographic modality for assessment of mandibular third molars is stereo-scanography, but the diagnostic accuracy of this technique has only been addressed in a few studies [7–9]. In one study, the seven signs of direct contact in panoramic images

Correspondence: Louise Hauge Matzen, DDS, PhD student, Section of Oral Radiology, Department of Dentistry, Aarhus University, Vennelyst Boulevard 9, DK-8000 Aarhus C, Denmark. Tel: +45 871 67 457. E-mail: louise.hauge.matzen@odontologi.au.dk

(Received 7 September 2012; revised 23 November 2012; accepted 14 December 2012)

ISSN 0001-6357 print/ISSN 1502-3850 online © 2013 Informa Healthcare
DOI: 10.3109/00016357.2013.764574

were compared with the findings from stereoscopic visualization of stereo-scanograms both validated against the surgical findings. It was concluded that the stereographic technique was a useful method with a higher sensitivity than panoramic imaging [8]. Stereo-scanograms have also been compared with panoramic images plus a series of three intra-oral images (orthogonal and eccentric) [7]. It was concluded that stereo-scanograms were more accurate when validated against the surgical findings for the position of the tooth and number of roots, while both methods were equally accurate in determining the relationship between the roots and the mandibular canal [7].

Recently, cone beam computed tomography (CBCT) has become available and it has been claimed that the diagnostic accuracy of this method is superior to panoramic images [10–14]. However, these studies have used the CBCT findings as a 'gold standard' for the panoramic findings and obviously CBCT will be more accurate. In contrast, a review by Guerrero et al. [15] concluded that CBCT should not be used as a reference standard since, being a diagnostic method, it in itself is apt to both false positive and false negative recordings. Therefore, intra-operative findings or sensory disturbances from the inferior alveolar nerve (IAN) should still be the reference when determining proximity between the third molar and the mandibular canal by radiographic methods. Furthermore, in this review only two studies were reported, which fulfilled that criterion [16,17]. In a recent study the accuracy of panoramic images, stereo-scanograms and CBCT was validated against the surgical findings. The study included only 18 teeth [9] and further studies are thus needed to assess the accuracy of CBCT for third molar assessment. Therefore, the aim of this study was to compare the diagnostic accuracy of panoramic images, stereo-scanograms and CBCT for assessment of tooth angulation, root number and morphology of mandibular third molars and the relationship to the mandibular canal before surgery using intra-operative findings and sensory disturbances as validation.

Material and methods

Patients

The study was approved by the local Committee of Ethics, Denmark. A total of 294 patients (with 565 mandibular third molars) underwent a clinical examination and were screened for participation in this study. The patients were recruited from the Section of Oral and Maxillofacial Surgery and Oral Pathology, Department of Dentistry, Aarhus University, Denmark, to have one or two mandibular third molars surgically removed. A panoramic radiograph or intra-oral images were available for the clinical examination. The panoramic radiograph was either included in the referral records of the patient from the general practitioner or a panoramic examination was performed at the Section of Oral Radiology, Department of Dentistry, Aarhus University, Denmark, using either a Cranex Tome unit (Soredex, Helsinki, Finland) with a phosphor plate image receptor (Digora image plate and PCT scanner, Soredex, Helsinki, Finland) or a ProMax unit (Planmeca, Helsinki, Finland) with a CCD-based image receptor.

After the clinical examination it was decided whether surgical removal was indicated. Indications for removal were: (1) recurring episodes of pericoronitis (≥2 episodes), (2) caries or resorption of the second molar (distal surface), (3) unrestorable caries of the third molar, (4) progressive marginal bone loss of the second molar (distal surface) or (5) other pathologic conditions related to the third molar. Only third molars scheduled for removal, with over-projection of the roots/parts of the tooth and the mandibular canal in the initial image, were included. The study eventually included 147 mandibular third molars (68 left and 79 right side molars) in 112 patients (58 males and 54 females, mean age = 25.1 years, range = 18.2–44.2). For 139 teeth a panoramic image was available and eight teeth had sufficient intra-oral images, thus no panoramic image was recorded. The patients were all referred to the Section of Oral Radiology for additional radiographic examinations.

Radiographic examinations

The additional radiographic examinations consisted of stereo-scanography and a CBCT examination. A Scanora unit (Soredex, Helsinki, Finland) was used for scanography and the image receptor was a Digora phosphor plate. The stereo-scanograms consisted of a series of four images (stereo-scopic multiview), which displayed the third molar in one orthogonal and one disto-eccentric projection and two projections cranial to these [18]. In both directions the tube shift angle was 4°. This technique allows for viewing with stereopsis [18] in addition to the tube-shift technique for assessment of the relation between the tooth and the mandibular canal.

Two CBCT units were used for the CBCT examinations, either the NewTom 3G (QR SRL, Verona, Italy) (65 third molars) or the Scanora 3D (Soredex, Helsinki, Finland) (82 third molars). In the NewTom scanner, the patients were examined with a 6-inch FOV and in the Scanora 3D with a 6 × 6 cm FOV. The FOV was centered at the mandibular third molar region. Unfortunately, the NewTom 3G was not available in the last part of the period for patient inclusion, which is why more third molars were examined with the Scanora 3D.

The stereo-scanograms and panoramic images were exported from their dedicated software and viewed in general software (DigiView PACS) [19] with possibilities to use zoom function and image enhancement such as brightness, contrast and gamma curve functions. The CBCT volumetric data sets were reconstructed to display 2D images (NewTom: 0.2 mm sections; Scanora 3D: 0.13 mm sections) in three planes: axial, sagittal and coronal, and viewed in their dedicated software (NewTom 3G: NNT, QR SRL, Verona, Italy; Scanora 3D: OnDemand®, Cypermed Inc., Irvine, CA). All images were assessed on flat-panel 19 or 20 inch quality monitors (SyncMaster 203B (Samsung, Cheonan City, Korea), Olorin VistaLine (Olorin AB, Kungsbacka, Sweden) or Phillips 190S (Eindhoven, The Netherlands)).

Radiographic assessment

The assessment of the images was incorporated in the daily clinical practice at the Section of Oral Radiology and three specialist observers took part in the assessment of the images (two oral radiologists and one PhD student in oral radiology, who assessed the vast majority of the images). The PhD student had 4 years of experience in interpreting panoramic images, stereo-scanograms and CBCT images of mandibular third molars and was trained and calibrated by the two specialists before the beginning of the study. The following tooth-related variables for the third molar in question were recorded: (1) angulation (horizontal/disto-angulated/mesio-angulated/vertical), (2) number of roots (1/2/> 2), (3) root morphology of the distal and mesial root (assessed separately) (straight/buccal-/lingual-/distal-/mesial bending) and (4) relation to the mandibular canal (direct contact/no direct contact) for each radiographic modality.

In the panoramic images the relation to the mandibular canal was interpreted as direct contact if one of the following three signs was visible: (1) interruption of the white line of the border of the canal, (2) diversion of the canal and/or (3) darkening of the roots [6]. In the stereo-scanograms direct contact to the canal was recorded, if the roots/parts of the tooth were positioned in the same level in the bucco-lingual plane viewed with stereopsis or the tube shift technique. In the CBCT a direct contact to the canal was recorded, if there was no bony separation between the roots/parts of the tooth and the mandibular canal. Whenever there was doubt about any variable, a consensus between two observers was made and recorded.

Surgical treatment

The patients were given ibuprofen (600 mg) and performed mouth-rinsing for 1 min with a 0.12% chlorhexidine solution pre-operatively. A standard buccal flap approach was used for the surgical procedures. After raising a full-thickness mucoperiostal flap, buccal/distal bone was removed with a burr under sterile saline irrigation. The tooth was removed in one piece or several pieces after sectioning with a burr also under sterile saline irrigation. Inflammatory tissue and sharp bone edges were removed before meticulous irrigation of the extraction socket and the operation field. Finally, the flap was repositioned and sutured using 2–3 resorbable sutures (Vicryl 4-0, Ethicon, Germany).

The patients were given standard post-operative information and a prescription for 600 mg ibuprofen to be taken up to 3-times daily as needed. In addition, the patients were instructed to perform mouth-rinsing with 0.12% chlorhexidine solution twice daily until control examination and removal of the sutures 1 week post-operatively.

Intra- and post-operative assessment

During/after surgery the same tooth-related variables as for the radiographic assessment were registered and these served as validation for the radiographic findings: (1) angulation (horizontal/disto-angulated/mesio-angulated/vertical), (2) number of roots (1/2/> 2), (3) root morphology of the distal and mesial root (assessed separately) (straight/buccal-/lingual-/distal-/mesial bending) and (4) relation to the mandibular canal (direct contact/no direct contact). Direct contact between the roots of the tooth and the mandibular canal was registered if one or more of the following criteria were fulfilled: (1) the IAN was visible in the extraction socket, (2) grooves/impressions from the canal were seen in the root complex or (3) the patient had sensory disturbance in the innervation area of the IAN 1 week post-operatively.

Data treatment

Root morphology was re-coded for the mesial and distal root components separately in three ways: (1) bending/no bending, (2) buccal or lingual bending/no buccal or lingual bending and (3) mesial or distal bending/no mesial or distal bending. These re-coded categories were all tested separately. Since it is not possible to examine buccal and lingual bending of the roots in panoramic images, the second re-coding and tests were only performed between recordings in stereo-scanograms and CBCT images.

Accuracy was defined as agreement between the radiographic and the intra-/post-operative findings. McNemar's chi-squared test was used to assess differences in accuracy between the two CBCT units for all parameters. A linear regression model was used to assess the overall accuracy between the three modalities and McNemar's chi-squared test was

Table I. Distribution of the radiographic vs the intra- and post-operative findings.

	Panoramic image (n = 139)	Stereo-scanogram (n = 147)	CBCT (n = 147)
Angulation			
Horizontal	22/26 (84.6)	24/27 (88.9)	23/27 (85.2)
Disto-angulated	18/24 (75)	20/24 (83.3)	16/24 (66.7)
Mesio-angulated	40/44 (90.9)	47/49 (95.9)	43/49 (87.8)
Vertical	29/45 (64.4)	29/47 (61.7)	37/47 (78.7)
Number of roots			
1	9/28 (32.1)	11/30 (36.7)	12/30 (40)
2	83/97 (85.6)	91/102 (89.2)	88/102 (86.3)
>2	4/14 (28.6)	3/15 (20)	11/15 (73.3)
Distal root, bending			
Yes	41/70 (58.6)	48/73 (65.8)	45/73 (61.6)
No	53/67 (79.1)	56/72 (77.8)	59/72 (81.9)
Distal root, buccal or *lingual* bending			
Yes	—	2/11 (18.2)	4/11 (36.4)
No	—	124/134 (92.5)	128/134 (95.5)
Distal root, mesial or distal bending			
Yes	40/63 (63.5)	41/66 (62.1)	39/66 (59.1)
No	59/74 (79.7)	63/79 (79.8)	68/79 (86.1)
Mesial root, bending			
Yes	79/98 (80.6)	86/103 (83.5)	93/103 (90.3)
No	23/41 (56.1)	24/44 (54.6)	25/44 (56.8)
Mesial root, buccal or *lingual* bending			
Yes	—	6/13 (46.2)	7/13 (53.9)
No	—	114/134 (85.1)[a]	126/134 (94.0)[a]
Mesial root, mesial or distal bending			
Yes	75/92 (81.5)	74/96 (77.1)	82/96 (85.4)
No	25/47 (53.2)	31/51 (60.8)	30/51 (60.8)
Direct contact with the canal			
Yes	5/17 (29.4)	12/21 (57.1)	14/21 (66.7)
No	95/122 (77.9)[b]	67/126 (53.2)[b,c]	86/126 (68.3)[c]

Accuracy tested between modalities; [a]p = 0.02; [b]p = 0.002; [c]p = 0.004.
Percentage of agreement in brackets.

used to assess differences in accuracy between the modalities two-by-two for all variables.

Sensitivity of the radiographic modalities to display if a direct contact between the tooth and the mandibular canal was present (number with direct contact observed in radiographs/number with operative findings of direct contact or sensory disturbances) and specificity of the radiographic modalities to exclude a direct contact between the tooth and the canal (number with no direct contact observed in radiographs/number with no operative findings of direct contact or no sensory disturbances) were calculated. A regression model was used to assess differences in sensitivity and specificity, respectively, between the three modalities. The data were analyzed using Stata 10.0 (StataCorp LP, College Station, Texas) and a 5% level of significance was applied.

Results

In two cases the root tip of the distal root was not removed due to fracture; consequently, morphological assessment of the distal root could not be performed. Therefore, the final number of recordings of the distal root was 137 for panoramic images and 145 for stereo-scanograms and CBCT. There was no significant difference between the two CBCT units for any parameter ($p > 0.05$). Therefore, CBCT was treated as one modality in the following analyses.

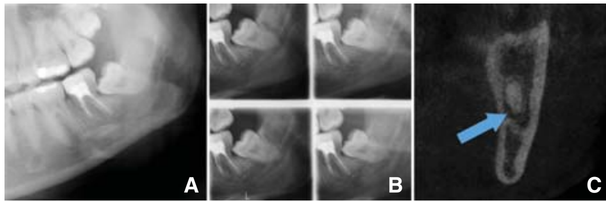

Figure 1. Left mandibular third molar: (A) panoramic image; (B) Stereo-scanogram; (C) CBCT section coronal view. Arrow indicates the mandibular canal.

In Table I, the distribution of the radiographic vs the intra- and post-operative findings for all variables for the three modalities is shown. The results from the linear regression analyses and for McNemar's chi-squared test for accuracy between the three modalities showed no significant differences between any modality for the following parameters: (1) angulation, (2) number of roots and (3) root morphology in the mesio-distal plane. There was, however, a statistically significant difference between CBCT and stereo-scanograms for detection of buccal or lingual bending of the mesial root ($p = 0.02$), which means that CBCT had a higher accuracy than stereo-scanograms for assessing this parameter. A significant difference was also seen between panoramic images and stereo-scanograms ($p = 0.002$) and between CBCT and stereo-scanograms ($p = 0.004$) for assessment of the relationship to the mandibular canal. This means that panoramic images and CBCT had a higher accuracy than stereo-scanograms for assessing this parameter.

When accuracy was additionally assessed as sensitivity and specificity for the three modalities, sensitivity for a direct contact between the roots of the third molar and the mandibular canal was highest for CBCT (0.67), thereafter stereo-scanograms (0.57) and lowest for panoramic images (0.29). This difference was significant between the panoramic images and CBCT ($p = 0.05$). The specificity for no direct contact between the tooth and the mandibular canal was highest for panoramic images (0.78), thereafter CBCT (0.68) and lowest for stereo-scanograms (0.53). This difference was significant between panoramic images and stereo-scanograms and between CBCT and stereo-scanograms ($p < 0.001$). Figure 1 shows a representative example of a third molar with no signs of close contact in the panoramic image, but direct contact was determined both in the stereo-scanograms and in the CBCT images. The IAN was visible in the extraction socket after removal of this tooth, i.e. the assessments in stereo-scanograms and CBCT were true positives.

Discussion

To assess the diagnostic accuracy of a radiographic modality, a validation method or reference standard is mandatory to compare the radiographic findings with the true situation. For mandibular third molars the convention has been to validate the radiographic observations against the intra- and post-operative findings. This validation method is considered to be reliable for tooth-related parameters (angulation, number and bending of roots) since it is possible to inspect the tooth and roots after removal of the tooth. Panoramic images have previously been found to be useful in determining the impaction state and angulation of the tooth, but the accuracy for number and morphology of roots was poor [2,3]. Stereo-scanograms have been found to be more accurate than a panoramic image plus a series of eccentric intra-oral images in determining angulation and number of roots [7]. Suomalainen et al. [9] found that CBCT revealed the number of roots more reliably than panoramic images. No statistically significant difference was found in the present study between the three modalities for assessing tooth angulation and number of roots, but CBCT was more accurate compared to stereo-scanograms to assess bending in the bucco-lingual plane. As might be expected, CBCT can therefore be useful for adding information on root morphology.

It can be questioned whether the validation criterion that the IAN must be visible intra-operatively is reliable for assessment of whether or not a direct contact to the IAN exists. The clinical inspection of the empty alveolus may not be valid in determining whether or not there is bony separation between the roots of the third molar and the nerve. It can be speculated that there may be false negative recordings, namely cases where the nerve was not visible after removal of the tooth, but still there could have been no bony separation, equaling a direct contact, between the root and the mandibular canal. To avoid IAN injury the assessment involved exclusively visual inspection, therefore, the existence of direct contact may be under-estimated. This means that the strength of the truly negative observation may be weak. On the other hand, the strength of the truly positive observation (cases where the nerve was actually visible) is thought to be high. After removal of the tooth it is moreover possible to examine the root complex for grooves related to the IAN and this sign may also be interpreted as indicative for a direct contact between the tooth and the nerve. Furthermore, a patient-related outcome (sensory disturbance in the area of innervation from the IAN) may indicate a direct contact between the tooth and the nerve. The validity of this criterion can also be discussed, since a change in sensory feeling post-operatively may arise from other factors than direct contact to the IAN, for example during injection of anesthetics. If sensitivities for a direct contact were tested using only operative findings as signs for direct contact, this would result in a probability value of 6% between panoramic images (sensitivity 0.27) and CBCT (sensitivity 0.63). The

two patients with sensory disturbances had no operative signs of a direct contact. In a recent review based on five studies assessing the seven signs for a close contact between the roots of the molar and the mandibular canal in a panoramic image, sensory disturbance was used as the reference standard in three of the studies, while IAN exposure observed after removal of the tooth was used as the validation for a close contact in two studies. Both validation methods were stated in the review [5,6] as adequate reference standards for a close relation to the mandibular canal and they have been used for decades in evidence-based dentistry [20]; therefore, they were also used in the present study. Two of the three studies which used sensory disturbances as the sign of close contact were retrospective case-control studies [21,22] and the study by Rood and Shehab [4] included both a retrospective and a prospective survey, but for all of them no operative findings were used to indicate direct/no direct contact to the IAN, which conversely was used in the last two studies [1,23] included in the review. Even with the drawbacks of these validation criteria taken into account, we believe that the validation methods can be used for a relative comparison between the sensitivities of radiographic modalities when assessed within the same study and the same operators. The absolute values of sensitivities may, however, be difficult to compare between studies.

When using these validation criteria, CBCT had the highest sensitivity and panoramic images the lowest for assessment of a direct contact to the nerve in our study. This means that the probability that CBCT would assess a direct contact between the tooth and the mandibular canal when a direct contact to the nerve truly existed was on average 67%, which was significantly higher than panoramic images where the probability was 29%. With the number of cases with direct contact (21 teeth) in this study, there was no difference in sensitivity between stereo-scanograms and CBCT and between stereo-scanograms and panoramic images. On the other hand, specificity, i.e. no direct contact between the tooth and the mandibular canal was recorded when no direct contact truly existed, was 68% in CBCT, 78% in panoramic images and 53% in stereo-scanograms. Thus, panoramic images and CBCT were not significantly different, but had higher specificities than stereo-scanograms. It is logical that, when the signs in panoramic images determining a direct relation were only present in a few cases, this will give rise to a high specificity. In the present context a diagnostic method with high sensitivity seems to be preferable over one with high specificity, since the consequences of a 'false positive' recording of a close contact between the tooth and the mandibular canal where this did not exist in reality, may often be that the surgeon is more meticulous during the surgical procedure. In contrast, it may be more critical with a 'false negative' radiographic recording, namely cases where an existing direct contact was not assessed with the radiographic modality.

Bell [1] found a sensitivity and specificity of panoramic images for determining the relation to the mandibular canal of 66% and 74%, respectively, using the seven signs for close relation between the tooth and the mandibular canal and the visibility of the IAN intra-operatively as the validation criterion. Wenzel et al. [7] stated that stereo-scanography (sensitivity: 0.44, specificity: 0.91) and a panoramic image plus a series of eccentric intra-oral images (sensitivity: 0.53, specificity: 0.88) had the same accuracy for demonstrating the relation to the mandibular canal. In contrast, Tammisalo et al. [8] concluded that stereo-scanograms had a higher sensitivity in determining the relation to the mandibular canal than panoramic images (0.91 vs 0.56). In another study by Tantanapornkul et al. [16] on 142 teeth, it was concluded that CBCT (sensitivity: 93%, specificity: 77%) was significantly superior to panoramic images (sensitivity: 70%, specificity: 63%) in predicting nerve exposure during removal of mandibular third molars. The sensitivities and specificities found in this study were higher than in the present study, but, besides possible operator variation in the validation of direct contact, excessive bleeding caused by the relation between the root and the IAN could not be evaluated in several cases, which were then omitted. Suomalainen and coworkers found that CBCT was more reliable than scanograms in determining the relation to the mandibular canal. However, no data on sensitivity or specificity were given.

The relation to the mandibular canal may be one of the most important parameters to assess before surgical removal of mandibular third molars and a close contact may be decisive for the choice of surgical treatment [24] to minimize the risk of IAN injury. It has recently been recommended to perform coronectomy, where only the crown of the tooth is removed, in cases where there is a close relation in the panoramic image [25–30]. In a recent study it was concluded that no bony separation between the roots of the third molar and the mandibular canal observed in CBCT images was a highly significant factor for choosing coronectomy instead of removal of the whole tooth [24].

In the present study only two patients (1.36%) had a temporary sensory disturbance after removal of the tooth (data not shown). One of the teeth was assessed with no close contact in the panoramic images and stereo-scanogram, but there was no bony separation between the roots and the mandibular canal in the CBCT images. The other tooth was assessed to be in direct contact with the canal in all three radiographic modalities. Although our findings encourage the use of CBCT before removal of mandibular third molars, large randomized controlled clinical trials are needed

to address whether fewer IAN injuries will be the result of CBCT examinations compared to merely panoramic or scanographic examination. Such studies may demand large patient samples and, thus, be quite cumbersome to conduct [31].

In conclusion, when comparing the diagnostic accuracy of panoramic radiography, stereo-scanography and CBCT for assessment of mandibular third molars, CBCT was superior to determine the existence of a direct contact between the roots of the mandibular third molar and the mandibular canal and to assess bending of roots in the bucco-lingual plane. There were no differences between the three modalities for assessing tooth angulation, number of roots and bending of the roots in the mesio-distal plane.

Acknowledgments

The authors would like to thank 'Calcinfonden' for financial support. The staff at the Section of Oral Radiology and Section of Oral and Maxillofacial Surgery and Oral Pathology, Department of Dentistry, Health, Aarhus University are thanked for their help during the period of data sampling. Especially Bjarne Simonsen, Jens Hartlev and Birgit Kenrad are thanked for support with the surgical procedures.

Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

References

[1] Bell GW. Use of dental panoramic tomographs to predict the relation between mandibular third molar teeth and the inferior alveolar nerve. Radiological and surgical findings and clinical outcome. Br J Oral Maxillofac Surg 2004;42:21–7.

[2] Bell GW, Rodgers JM, Grime RJ, Edwards KL, Hahn MR, Dorman ML, et al. The accuracy of dental panoramic tomographs in determining the root morphology of mandibular third molar teeth before surgery. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;95:119–25.

[3] Benediktsdottir IS, Hintze H, Petersen JK, Wenzel A. Accuracy of digital and film panoramic radiographs for assessment of position and morphology of mandibular third molars and prevalence of dental anomalies and pathologies. Dentomaxillofac Radiol 2003;32:109–15.

[4] Rood JP, Shehab BA. The radiological prediction of inferior alveolar nerve injury during third molar surgery. Br J Oral Maxillofac Surg 1990;28:20–5.

[5] Atieh MA. Diagnostic accuracy of panoramic radiography in determining relationship between inferior alveolar nerve and mandibular third molar. J Oral Maxillofac Surg 2010;68:74–82.

[6] Wenzel A. It is not clear whether commonly used radiographic markers in panoramic images possess predictive ability for determining the relationship between the inferior alveolar nerve and the mandibular third molar. J Evid Based Dent Pract 2010;10:232–4.

[7] Wenzel A, Aagaard E, Sindet-Pedersen S. Evaluation of a new radiographic technique: diagnostic accuracy for mandibular third molars. Dentomaxillofac Radiol 1998;27:255–63.

[8] Tammisalo T, Happonen RP, Tammisalo EH. Stereographic assessment of mandibular canal in relation to the roots of impacted lower third molar using multiprojection narrow beam radiography. Int J Oral Maxillofac Surg 1992;21:85–9.

[9] Suomalainen A, Venta I, Mattila M, Turtola L, Vehmas T, Peltola JS. Reliability of CBCT and other radiographic methods in preoperative evaluation of lower third molars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010;109:276–84.

[10] Tantanapornkul W, Okochi K, Bhakdinaronk A, Ohbayashi N, Kurabayashi T. Correlation of darkening of impacted mandibular third molar root on digital panoramic images with cone beam computed tomography findings. Dentomaxillofac Radiol 2009;38:11–16.

[11] Monaco G, Montevecchi M, Bonetti GA, Gatto MR, Checchi L. Reliability of panoramic radiography in evaluating the topographic relationship between the mandibular canal and impacted third molars. J Am Dent Assoc 2004; 135:312–18.

[12] Nakagawa Y, Ishii H, Nomura Y, Watanabe NY, Hoshiba D, Kobayashi K, et al. Third molar position: reliability of panoramic radiography. J Oral Maxillofac Surg 2007;65:1303–8.

[13] Neugebauer J, Shirani R, Mischkowski RA, Ritter L, Scheer M, Keeve E, et al. Comparison of cone-beam volumetric imaging and combined plain radiographs for localization of the mandibular canal before removal of impacted lower third molars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2008;105:633; 642; discussion 643.

[14] Nakamori K, Fujiwara K, Miyazaki A, Tomihara K, Tsuji M, Nakai M, et al. Clinical assessment of the relationship between the third molar and the inferior alveolar canal using panoramic images and computed tomography. J Oral Maxillofac Surg 2008;66:2308–13.

[15] Guerrero ME, Shahbazian M, Elsiena Bekkering G, Nackaerts O, Jacobs R, Horner K. The diagnostic efficacy of cone beam CT for impacted teeth and associated features: a systematic review. J Oral Rehabil 2011;38:208–16.

[16] Tantanapornkul W, Okouchi K, Fujiwara Y, Yamashiro M, Maruoka Y, Ohbayashi N, et al. A comparative study of cone-beam computed tomography and conventional panoramic radiography in assessing the topographic relationship between the mandibular canal and impacted third molars. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007; 103:253–9.

[17] Ghaeminia H, Meijer GJ, Soehardi A, Borstlap WA, Mulder J, Berge SJ. Position of the impacted third molar in relation to the mandibular canal. Diagnostic accuracy of cone beam computed tomography compared with panoramic radiography. Int J Oral Maxillofac Surg 2009;38:964–71.

[18] Wenzel A. Dental students' ability for three-dimensional perception of two-dimensional images using natural stereopsis: its impact on radiographic localization. Dentomaxillofac Radiol 1999;28:98–104.

[19] Gotfredsen E, Wenzel A. Integration of multiple direct digital imaging sources in a picture archiving and communication system (PACS). Dentomaxillofac Radiol 2003;32:337–42.

[20] Azaz B, Shteyer A, Piamenta M. Radiographic and clinical manifestations of the impacted mandibular third molar. Int J Oral Surg 1976;5:153–60.

[21] Blaeser BF, August MA, Donoff RB, Kaban LB, Dodson TB. Panoramic radiographic risk factors for inferior alveolar nerve injury after third molar extraction. J Oral Maxillofac Surg 2003;61:417–21.

[22] Gomes AC, Vasconcelos BC, Silva ED, Caldas Ade F Jr, Pita Neto IC. Sensitivity and specificity of pantomography to predict inferior alveolar nerve damage during extraction of impacted lower third molars. J Oral Maxillofac Surg 2008;66: 256–9.

[23] Sedaghatfar M, August MA, Dodson TB. Panoramic radiographic findings as predictors of inferior alveolar nerve exposure following third molar extraction. J Oral Maxillofac Surg 2005;63:3–7.

[24] Matzen LH, Christensen J, Hintze H, Schou S, Wenzel A. Influence of cone beam CT for treatment plan before surgical intervention of mandibular third molars and impact of radiographic factors on deciding on coronectomy versus surgical removal. Dentomaxillofac Radiol 2013;42:98870341.

[25] Cilasun U, Yildirim T, Guzeldemir E, Pektas ZO. Coronectomy in patients with high risk of inferior alveolar nerve injury diagnosed by computed tomography. J Oral Maxillofac Surg 2011;69:1557–61.

[26] Dolanmaz D, Yildirim G, Isik K, Kucuk K, Ozturk A. A preferable technique for protecting the inferior alveolar nerve: coronectomy. J Oral Maxillofac Surg 2009;67:1234–8.

[27] Leung YY, Cheung LK. Safety of coronectomy versus excision of wisdom teeth: a randomized controlled trial. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2009;108:821–7.

[28] Leung YY, Cheung LK. Can coronectomy of wisdom teeth reduce the incidence of inferior dental nerve injury? Ann R Australas Coll Dent Surg 2008;19:50–1.

[29] Pogrel MA. Partial odontectomy. Oral Maxillofac Surg Clin North Am 2007;19:85–91.

[30] Renton T, Hankins M, Sproate C, McGurk M. A randomised controlled clinical trial to compare the incidence of injury to the inferior alveolar nerve as a result of coronectomy and removal of mandibular third molars. Br J Oral Maxillofac Surg 2005;43:7–12.

[31] Roeder F, Wachtlin D, Schulze R. Necessity of 3D visualization for the removal of lower wisdom teeth: required sample size to prove non-inferiority of panoramic radiography compared to CBCT. Clin Oral Investig 2012;16: 699–706.