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Original Article

Comparison of periapical radiography, panoramic radiography, and cone-beam computed tomography for detecting implant-related injuries to the inferior alveolar canal: An *ex vivo* study

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ABSTRACT

Background: The aim of this study was to evaluate the diagnostic potential of periapical radiograph, panoramic radiograph, and cone-beam computed tomography (CBCT) in detecting implant-related perforation of the inferior alveolar canals.

Materials and Methods: In this *ex vivo* study, a total of 45 dental implants were placed in 15 sheep hemimandibles simulating two types of injuries to the inferior alveolar canal: pilot drill injury and implant penetration into the canal. Fifteen implants were placed as the control group with 1 mm distance from the inferior alveolar nerve (IAN) canal roof. An imaging phantom was prepared by placing implant-containing blocks in the posterior mandibular area on both sides of an artificial model of the cranium. Panoramic and periapical radiographs as well as CBCT scans were obtained from the imaging phantom. Two independent observers repeated image analysis over two sessions. The area under the receiver operating characteristic curve (AUC) was used to determine diagnostic accuracy. Interobserver and intraobserver agreements were obtained using Cohen's kappa ($\alpha = 0.05$).

Results: For detection of pilot drill injuries by observer 1, CBCT (AUC = 1) and periapical radiograph (AUC = 0.889) were significantly better than using panoramic radiographs (AUC = 0.694) ($P < 0.001$ and $P = 0.014$, respectively). For observer 2, CBCT (AUC = 0.897) was also superior to panoramic radiography (AUC = 0.683) for this purpose ($P = 0.018$). For detection of penetrative injuries to the IAN canal, periapical radiography had an AUC of 0.995 and 0.986 for observers 1 and 2, respectively, while the AUC for panoramic radiography was 0.990 and 0.948 for observers 1 and 2, respectively. The corresponding values using CBCT were 1.000 and 0.995, respectively. No significant difference was observed between the three modalities for detection of penetrative injuries ($P > 0.05$).

Conclusion: CBCT was better in detecting pilot drill injuries to the IAN canal compared to panoramic radiograph. Therefore, in cases where clinical presentations suggest IAN disturbances, CBCT scan

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should be preferred. However, the diagnostic potential of periapical radiograph, panoramic radiograph, and CBCT was not significantly different for detection of penetrative injuries to the IAN canal.

Key Words: Cone-beam computed tomography, dental implants, mandibular canal, panoramic radiograph, periapical radiograph

INTRODUCTION

Dental implants are widely used for the replacement of missing teeth in modern dentistry.[1,2] Accurate placement of dental implants that avoid vital structures such as the maxillary sinus, the mental foramen, and the inferior alveolar nerve (IAN) canal is of utmost importance. A minimum distance of 2 mm between the implant and these structures has been suggested.[3] Studies report that the prevalence of injuries to the IAN during and after insertion of dental implants is as high as 13%.[4-6] Mechanical, chemical, and thermal factors can lead to IAN damage during implant placement. Implant drills, implant tip, and bone debris are among the most common mechanical reasons for IAN injuries, which can result in pressure, entrapment, or dissection of the nerve.[7] These injuries can lead to clinical complaints such as anesthesia, hypoesthesia, dysesthesia, and pain. If these clinical symptoms last for a while, they can affect the patient's quality of life and result in legal cases for practitioners.[8] Therefore, accurate diagnosis of injuries to the IAN from implant placement is very important.

Radiographic examinations are performed at different stages of implant treatments, for treatment planning, fabrication of implant guides, and follow-up of inserted implants.[9] Two-dimensional radiographs, such as panoramic and periapical radiographs, have limitations such as distortion, magnification, superimposition of anatomic structures, and inability to visualize the buccolingual width. Cone-beam computed tomography (CBCT), however, can provide three-dimensional (3D) information, which can overcome the limitations of conventional plain radiographs. Assessment of bone quality and quantity and 3D visualization of supporting bone and adjacent structures are provided in CBCT images of the desired implant sites. CBCT can also provide valuable information about the relationship between inserted dental implants and adjacent anatomic structures.[10,11] Nevertheless, CBCT is prone to artifacts, which can degrade the quality of images in different ways. Vanderstuyft *et al*. reported that implants can show a blooming, i.e., increase in size, of 12% to 15% in CBCT images. Immediately buccal to the implant blooming area, a zone of 0.45 mm was observed in which the buccal bone was not always visible.[12] In addition, according to Benic *et al*., artifacts were always present adjacent to titanium implants regardless of implant position.[13] Therefore, it is important to evaluate the diagnostic ability of CBCT images in visualizing implant-related injuries to the IAN canal.

Limited studies have been performed on the potential of different imaging techniques in the diagnosis of implant-related injuries to the IAN. In 2020, Sirin *et al*. compared the accuracy of CBCT and panoramic radiography in detection of IAN canal damage. According to their findings, CBCT performed better in detecting the collapse of the superior border of the canal and pilot drill injuries. However, in cases with penetration of the implant tip to the IAN canal, no significant difference was observed between the two imaging modalities.[6] The aim of the present study was to compare the diagnostic ability of periapical radiographs, panoramic radiographs, and CBCT in detecting implant-related injuries to the IAN canal.

MATERIALS AND METHODS

This *ex vivo* study was approved by the Ethical Committee of Isfahan University of Medical Sciences (#IR. MUI. REC.1400.047, approval date: 9/29/2021).

Preparation of bone blocks containing implants and the imaging phantom

A sample size of 15 implants in each experimental and control group was needed based on the following equation, considering an alpha of 0.05 and a power of 75%:

$$n = \frac{z^2_{1-\frac{\alpha}{2}} P(1-P)}{d^2}$$

where z is the confidence level at 95%, d is the precision, and P is the expected proportion.

Fifteen fresh adult sheep hemimandibles were used in this study. *After removing the soft tissues from* *the bones, the regions anterior to the mandibular foramen were sectioned.* A preoperative radiograph was obtained from the bone samples using a size 4 imaging plate (Durr Dental, Bietigheim-Bissingen, Germany) to visualize the location and appearance of the IAN canal. Monocortical bone windows were prepared on the lingual side, the windows were carefully removed, and the superior border of the IAN canal was visualized.

A total of 45 dental implants (Bionik, Nik Kasht Asia, Tehran, Iran) made of commercially pure titanium were inserted according to the manufacturer's instructions. Two groups of implant-related injuries to the canal were simulated: (1) injury by the pilot drill (with a diameter of 2 mm) and (2) penetration of the implant tip into the IAN canal. Fifteen implants were inserted for each group using direct vision from the prepared window. For the pilot drill injury, the superior border of the IAN canal was penetrated using the pilot drill. However, the implant was placed 1 mm above the superior border of the canal. To simulate the penetration of the implant tip into the inferior alveolar canal, the implant tip was placed 1 mm into the canal. Fifteen implants were used for the control group, where the implant tip was placed 1 mm above the superior border of the nerve canal, and no pilot drill injury was performed during the drilling procedure.[14]

A cranium model (Anatokala, Tehran, Iran) with the maxilla and mandible in occlusion was prepared. The posterior segment of the mandible was excised with preservation of the inferior border of the mandible. The sectioned portion of the sheep hemimandibles with inserted implants was then located and secured in the prepared cranium model. Soft tissue was simulated using 15 mm of red wax (Polywax, Izmir, Turkey) to make the phantom ready for imaging.[15]

Radiographic examination

Digital periapical radiographs were obtained by an intraoral radiographic unit (Planmeca, Helsinki, Finland) with the parallel technique using size 2 intraoral imaging plates (Durr Dental, Bietigheim-Bissingen, Germany) and film-holders (Kerr, CA, USA) with exposure parameters of 63 kVp, 8 mA, and 0.1 s. The periapical images were viewed. The phantom was positioned for obtaining panoramic radiographs with the Frankfurt plane placed parallel to the horizontal plane and the mid-sagittal plane perpendicular to it. Panoramic radiography was obtained using the ProMax unit (Planmeca, Helsinki, Finland) with exposure parameters of 64 kVp, 5 mA, and 15.6 s. The same position of the skull phantom was replicated for obtaining CBCT images using a Galileos CBCT scanner (Sirona, Bensheim, Germany) with parameters of 85 kVp, 21 mAs, 280 µm voxel size, and field of view of 15 cm × 15 cm [Figures 1-3].

Image interpretation

Images were viewed in the following software: digital periapical radiographs in Scanora (Soredex, Tuusula, Finland), digital panoramic radiographs in Romexis (Planmeca, Helsinki, Finland), and CBCT images in Sidexis 4 (Sirona, Bensheim, Germany). Two observers (a radiologist with 5 years of experience and an oral surgeon with 10 years of experience) performed the interpretation of images in a a quiet room with dim lighting. The observers were blind to the category of each image, and all images were displayed randomly for the observers. The

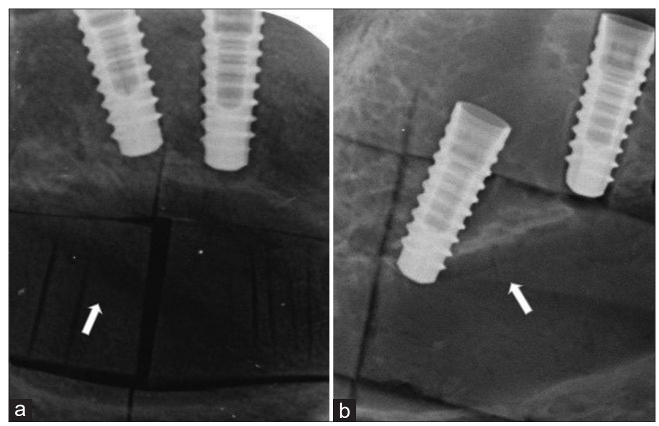

Figure 1: (a) Periapical radiographs of control implants, and (b) periapical radiographs of implants with pilot drill injury to the inferior alveolar nerve canal (right implant) and penetration of the inferior alveolar nerve canal (left implant). Arrows point to inferior alveolar nerve canal.

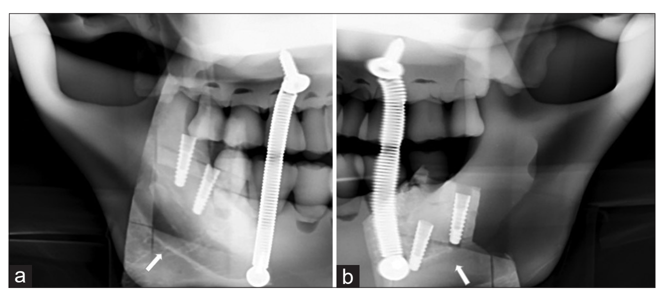

Figure 2: (a) Cropped panoramic radiographs of control implants, and (b) cropped panoramic radiographs of implants with pilot drill injury to the inferior alveolar nerve canal (right implant) and penetration of the inferior alveolar nerve canal (left implant). Arrows point to inferior alveolar nerve canal.

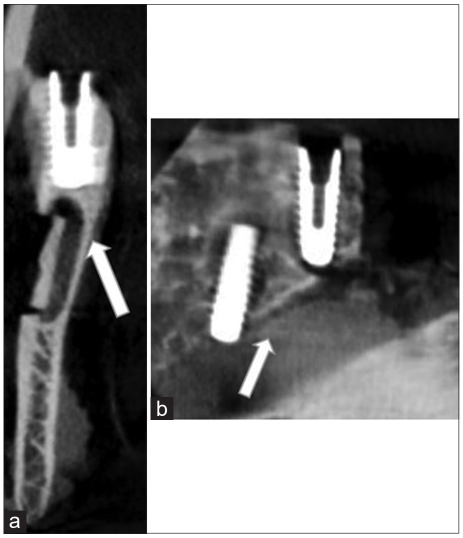

Figure 3: (a) Cross-sectional view of control implant, and (b) tangential cone-beam computed tomography views of implants with pilot drill injury to the inferior alveolar nerve canal (right implant) and penetration of the inferior alveolar nerve canal (left implant). Arrows point to inferior alveolar nerve canal.

observers were free to use different software options such as contrast, brightness, sharpen, and zoom. In addition, in the CBCT images, the observers could view the images in any desired view. For evaluating each implant, the observers were asked to determine whether canal injury was present or not, and also the type of injury present, i.e., pilot drill injury or penetration of the implant tip into the canal. The observers' responses were recorded using a 4-point Likert scale: (1) canal injury is absent, (2) pilot drill injury is present, (3) penetrative injury is present, and (4) uncertain. After 2 weeks, the observers were asked to evaluate 20% of the images once again.

Statistical analysis

Intraobserver and interobserver agreements were determined using Cohen's kappa. Images with score 4 (uncertain) were removed from further analysis. Diagnostic accuracy was calculated for each imaging modality using the area under the receiver operating characteristic curve (AUC). Statistical analysis was performed using SPSS software (version 25, IBM, NY, USA). In addition, AUC values of different modalities were compared using MedCalc statistical software version 19.2.6 (MedCalc Software Ltd., Ostend, Belgium; https://ww.medcalc.org; 2020). Level of significance was set at α =0.05. The roof of the IAN canal was intact below the control implants, and the observations for pilot drill and penetrative injuries to the IAN canal were combined and compared with the absence of injury. For the pilot drill and penetrative injuries, the observations for each injury were compared only with those of mandibles without any injury.

RESULTS

Intraobserver and interobserver agreements

For all implant groups and imaging modalities, the intraobserver agreements calculated by kappa values ranged from 0.860 to 1.00, indicating strong to almost perfect agreements.

Interobserver agreements determined by kappa values were strong to almost perfect (0.806–0.900) for periapical radiographs, moderate to strong for panoramic radiographs (0.544–0.772), and strong to almost perfect for CBCT image sets (0.746–0.903).

Area under the receiver operating characteristic curve values for each imaging modality

For detection of intact superior border of the IAN canal below the control implants, AUC values for observer 1 were 0.917, 0.817, and 1 for periapical radiograph, panoramic radiograph, and CBCT, respectively. These values for observer 2 were 0.850, 0.767, and 0.917 for periapical radiograph, panoramic radiograph, and CBCT, respectively [Table 1].

Pairwise comparison of the modalities showed that CBCT had a significantly higher AUC for detection of intact IAN canal roof below the control implants compared to panoramic radiography (P = 0.002 in observer 1 and P = 0.008 in observer 2). The other pairwise comparisons were not statistically significant ($P > 0.05$).

For detection of pilot drill injury to the IAN canal, AUC values for observer 1 were 0.889, 0.694, and 1 for periapical radiograph, panoramic radiograph, and CBCT, respectively. The corresponding values for observer 2 were 0.842, 0.683, and 0.897 [Table 2].

Pairwise comparison revealed that for detection of pilot drill injuries by observer 1, CBCT and periapical radiography were significantly better than panoramic radiography ($P < 0.001$ and P = 0.014, respectively). For observer 2, CBCT was superior to panoramic radiographs for this purpose (P = 0.018).

For detection of penetration of implant tip to the IAN canal, AUC values for observer 1 were 0.995, 0.990, and 1 for periapical radiography, panoramic radiography, and CBCT, respectively. The corresponding values for observer 2 were 0.986, 0.948, and 0.995 [Table 3].

Table 1: Area under the receiver operating characteristic curve for each observer in detecting intact roof canal below control implants

Imaging modality	AUC (SE)	95% CI
Observer 1		
Periapical radiograph	0.917 (0.049)	0.820–1.000
Panoramic radiograph	0.817 (0.069)	0.682–0.952
CBCT	1.000 (0.000)	1.000–1.000
Observer 2		
Periapical radiograph	0.850 (0.069)	0.715–0.985
Panoramic radiograph	0.767 (0.079)	0.611–0.922
CBCT	0.917 (0.055)	0.808–1.000

AUC: Area under the receiver operating characteristic curve; SE: Standard error; CI: Confidence interval; CBCT: Cone-beam computed tomography

Table 2: Area under the receiver operating characteristic curve for each observer in detecting pilot drill injury

Imaging modality	AUC (SE)	95% CI
Observer 1		
Periapical radiograph	0.889 (0.064)	0.708–0.976
Panoramic radiograph	0.694 (0.088)	0.489–0.856
CBCT	1.000 (0.000)	0.872–1.000
Observer 2		
Periapical radiograph	0.842 (0.073)	0.651–0.953
Panoramic radiograph	0.683 (0.097)	0.477–0.847
CBCT	0.890 (0.060)	0.719–0.980

AUC: Area under the receiver operating characteristic curve; SE: Standard error; CI: Confidence interval, CBCT: Cone-beam computed tomography

Table 3: Area under curve (AUC) for each observer in detecting penetration injury

Imaging modality	AUC (SE)	95% CI
Observer 1		
Periapical radiograph	0.995 (0.006)	0.872-1.000
Panoramic radiograph	0.990 (0.009)	0.863-1.000
CBCT	1.000 (0.000)	0.881–1.000
Observer 2		
Periapical radiograph	0.986 (0.012)	0.855-1.000
Panoramic radiograph	0.948 (0.040)	0.796-0.996
CBCT	0.990 (0.006)	0.872-1.000

AUC: Area under the receiver operating characteristic curve; SE: Standard error; CI: Confidence interval, CBCT: Cone-beam computed tomography

Pairwise comparison for AUC of different modalities for detection of penetrative injuries to the IAN canal revealed that for observers 1 and 2, no significant difference was noted between the three modalities in detecting penetration of implants to the IAN canal ($P > 0.05$).

DISCUSSION

Based on our findings, CBCT performed better than panoramic radiographs in visualizing pilot drill injuries to the IAN canal. However, for detecting penetration of implants into the IAN canal, the discriminatory performance of periapical, panoramic radiographs, and CBCT imaging was not significantly different.

Renton *et al*. reported 287 cases of iatrogenic injuries to the branches of the trigeminal nerve and found that more than 70% of the patients presented with a combination of neuropathic pain, numbness, and altered sensation. The authors have emphasized the negative effects of chin and lip paresthesia on different functions, such as shaving, eating, drinking, and kissing.[16] Treatment of these unfavorable presentations is time-consuming and difficult. It has been reported that more than 60% of patients with presentations of IAN injury did not show complete resolution.[17] Therefore, accurate diagnosis of the cause and nature of the injury is of the utmost importance.

In this study, periapical, panoramic, and CBCT images were used to evaluate the presence or absence of damage to the superior border of the IAN canal by dental implants and drills. These imaging modalities are the most common techniques used in different stages of treatment with dental implants, and evaluating their accuracy in these phases is valuable for determining their role in implantology. A panoramic radiograph is a combination of scanning and tomography and is therefore prone to distortion and superimposition, as well as loss of resolution for structures located outside the imaging layer or focal trough. In addition, linear measurements in panoramic radiographs are not accurate. Due to these shortcomings, the application of panoramic radiographs in implantology is better to be reserved only for when an overview of the implants and adjacent dentoalveolar structures is required. Periapical radiography can provide high-resolution images from implants and dentition with minimal radiation dose. Periapical radiographs obtained by the parallel technique using film holders can provide a view of the dentition with minimum distortion. However, they still have the disadvantages of 2D images, including superimposition. Neto *et al*. performed a systematic review comparing PA, panoramic, and CBCT imaging for peri-implant bone defects. They concluded that CBCT and PA provided excellent diagnostic accuracy, whereas panoramic radiography had significantly lower performance.[18] Sirin *et al*. conducted an *ex vivo* study comparing panoramic radiography and CBCT for detecting implant-related injuries to the inferior alveolar canal. They found that CBCT provided higher diagnostic accuracy and observer confidence for subtle injuries, while panoramic images sufficed for more overt cortical disruptions.[6] These results align with our conclusion that PA and CBCT are superior for identifying implant-related complications. Compating panoramic and PA images, the higher resolution of intraoral images provides an advantage in detecting finer details.[19]

Several studies have focused on the safety margin when discussing the proximity of dental implants to the IAN canal in different images. Basa and Dilek in their study evaluated the density and thickness of the superior border of the IAN canal in CBCT images. According to their findings, the cortical density of the canal borders has to be investigated prior to implant placement, as canals with thin walls cannot withstand the pressures of implant drilling and may collapse during implant insertion just above the canal roof.[20] Froum *et al*. evaluated 101 mandibular implants in 60 patients and concluded that the 2-mm distance between the implant and the borders of IAN canal might be overestimated, as in patients without neurologic symptoms, a mean distance of 0.75 mm was observed between the implant and the canal border.[21] Due to these observations, as well as the potential small linear and angular discrepancies between the measurements in CBCT images and surgical condition, it is wise to consider a safety margin of 2 mm in relation to the IAN for placement of dental implants in the posterior mandibular region.

In the present study, two of the most common types of injury to the IAN were simulated. In the penetrative injury to the IAN canal, the implant tip was located in the canal. Whereas, in the pilot drill injury, although the superior border of the canal was perforated by the implant drills, the final position of the implant remained above the canal outline. Based on the injury patterns simulated in the present study, neurosensory disturbances observed despite an apparent distance between the implant and the inferior alveolar nerve may be attributed to pilot drill–related injury or the transmission of occlusal forces to the canal. CBCT provides 3D visualization of structures and allows for better detection of localized perforations of the IAN canal's roof caused by pilot drill injuries compared with the 2D view of periapical and panoramic radiographs. While in penetrative injuries, with the implant tip completely in the IAN canal, panoramic radiography provided similar diagnostic potential as compared with periapical radiography and CBCT imaging.

To the authors' knowledge, only one previous study has been performed on the simulation of different types of injuries to the IAN and that has compared the diagnostic ability of different imaging modalities. Sirin *et al.* in 2020 have compared two modes of panoramic radiography, i.e., standard and dentition, as well as cross-sectional and multiplanar CBCT images. According to their findings, both modes of panoramic radiography were comparable to multiplanar and cross-sectional CBCT images in detection of implant penetration and collapse of the superior border of the IAN canal. However, for diagnosing pilot drill injuries, multiplanar and cross-sectional CBCT images provided higher accuracy values. For detecting pilot drill injuries, the diagnostic accuracy of panoramic radiography was 52% for standard mode and 60% for dentition mode. The accuracy of multiplanar and cross-sectional CBCT images for this injury was 85% and 90%, respectively. Moreover, for implant penetration, the diagnostic accuracy of panoramic radiography in standard mode, panoramic radiography in dentition mode, multiplanar CBCT images, and cross-sectional CBCT images was 85%, 80%, 87%, and 90%.[6] The findings of the study by Sirin *et al*. are generally in line with our findings, indicating superiority of CBCT over panoramic radiograph for detection of pilot drill injuries and similar performance of the two modalities in detection of penetration of implant tip to the IAN canal. In our study, the selected modalities were periapical, panoramic, and CBCT images. In addition, in the present study, different views of CBCT scans were not studied separately, and the observers were free to choose the desired views to reach a general conclusion. The reason for this was that an experienced observer generally uses a combination of different views and sections for diagnosis and confirmation of suspicious findings.

In 2019, Vanderstuyft *et al*. showed that in CBCT images, the implants show an increased size of about 12% to 15%. Based on the authors' findings, the presence of a doubtful zone was observed immediately buccal to the implant blooming, in which the buccal bone is not well detected.[12] Evaluation of the effects of implant blooming on detection of injuries to the IAN canal can complement the findings of this study. Potentially, a radiolucent area just below the implant tip can imitate a pilot drill injury to the IAN canal.

One of the limitations of this study is the potential difference between the bone density and shape and size of the IAN canal of sheep and human mandibles which can limit the generalization of the findings. In addition, using implants with different material and designs can alter the present results. Moreover, the diameter of the pilot drill in the implant drilling system determines the dimension of the pilot drill injury, making it easier or more difficult to detect. Further studies on these subjects are recommended with application of artifact reduction algorithms in CBCT images. In addition, performing similar studies using different implant materials such as zirconia is also suggested.

CONCLUSION

CBCT was better in detecting pilot drill injuries to the IAN canal compared to panoramic radiograph. Therefore, in cases where clinical presentations suggest IAN disturbances, CBCT scan should be preferred. However, the diagnostic potential of periapical radiograph, panoramic radiograph, and CBCT were not significantly different for detection of penetrative injuries to the IAN canal.

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Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or nonfinancial in this article.

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