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Ultrasonography for Diagnosis of Technical Implant Errors: A Pilot Study in Sheep Model

Teknik İmplant Hatalarının Tanısında Ultrasonografi: Koyun Modelinde Pilot Çalışma

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ABSTRACT

Objective: The aim of this study was to investigate technical implant errors with CBCT and ultrasonography and to evaluate the success of USG in demonstrating these errors.
Method: Two freshly cut sheep heads were obtained. A radiological examination was performed with both CBCT and USG before and after the dental implant placement. 10 implants (2 right, 3 left) were placed to represent a represent normal placement implant and 4 different complications: crestal bone defect, cortical bone perforation, mental foramen perforation, mandibular canal perforation.
Results: The implants placed in the normal position without complications could not be visualized by USG in both sheep heads. Perforation areas of implants in the cortical bone were visualized by USG in both samples. The mental foramen could be visualized preoperatively with USG, and the perforations caused by the implants in the mental foramen could also be visualized with USG. In addition, positive findings were obtained by USG in a crestal bone defect. Mandibular canal perforation could not be visualized by USG in both heads.
Conclusion: USG is a useful imaging method that can be used to quickly detect technical errors such as cortical perforation, mental foramen perforation, crestal bone loss, and placement outside the bone that occur during implant surgery.
Keywords: Cone-beam computed tomography, ultrasonography, dental implant

ÖZ

Amaç : Bu çalışmanın amacı CBCT ve ultrasonografi ile teknik implant hatalarını tespit etmek ve USG'nin bu hataları göstermedeki başarısını değerlendirmektir.
Yöntemler : İki adet taze kesilmiş koyun kafası elde edildi. Dental implant yerleştirme öncesi ve sonrasında hem CBCT hem de USG ile radyolojik inceleme yapıldı. Koyun kafalarının her birinde 2'şer dental implant sağda 3'er dental implant solda olmak üzere toplam 10 adet dental implant krestal kemik defekti, kortikal kemik perforasyonu, mental foramen perforasyonu, mandibular kanal perforasyonu olmak üzere 4 farklı komplikasyonu gösterebilmek amacıyla flepsiz teknikle yerleştirildi.
Bulgular : Normal pozisyonda komplikasyonsuz yerleştirilen implantlar her iki koyun kafasında da USG ile görüntülenemedi. Her iki örnekte de implantların kortikal kemikteki perforasyon alanları USG ile görüntülendi. USG ile ameliyat öncesinde mental foramen görüntülenebildiği gibi, implantların mental foramende neden olduğu perforasyonlar da USG ile görüntülenebildi. Ayrıca krestal kemik defektinde USG ile pozitif bulgular elde edildi. Her iki kafada da USG ile mandibular kanal perforasyonu görüntülenemedi.
Sonuç : USG, implant cerrahisi sırasında oluşan kortikal perforasyon, mental foramen perforasyonu, krestal kemik kaybı, kemik dışına yerleşim gibi teknik hataların hızlı bir şekilde tespit edilmesinde kullanılabilecek faydalı bir görüntüleme yöntemidir.
Anahtar kelimeler: Konik ışınlı bilgisayarlı tomografi, ultrasonografi, dental implant

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INTRODUCTION

Dental implants are an increasingly common treatment option used in the treatment of tooth deficiencies. There is an increase in the number and type of complications due to the increase in the number of applications, despite the high success rates of dental implants. While the term implant success describes an implant that is healthy and completely functional in the bone: Implant survival is described as the implant being in place.[1] Osseointegration is a straight structural and physiological connection between the bone and the functioning implant surface.[2–4] The condition of the marginal bone around the implant is directly effective in determining the success of the implant.[5] Resorption of more than half of the bone around the implant indicates failure of the implant.[2,6] Therefore, implant success is directly dependent on crestal bone resorption and is one of the most important determining factors for the post-operative success of implants.[3]

It is as effective as cortical bone resorption in terms of the success of the implant, as well as the technical errors made during the surgical application and planning. Technical errors include insufficient distance between the implants and neighboring structures, drilling of cortical bones, and drilling into anatomical points, and these might lead to complications like bone defects, unsuccessful osseointegration, bleeding, neurosensory disorders and extra operations and increase the likelihood of early or late implant failure.[7]

Cone-beam computed tomography (CBCT) is one of the most common imaging methods used to identify the connection between dentals implant and bones determine anatomical structures and their variations accurately, and display them in 3D.[8] CBCT is frequently used for determining places of implants.[9] Also, it has an advantage, when compared in terms of radiation dose. For example, the total radiation dose in two-dimensional radiographs such as full-mouth series intraoral, lateral cephalometric, and panoramic radiographs is between 43.2 and 200.6 µSv; this dose is between 995 and 1160 µSv for CT and 30 and 68 µSv for CBCT.[10]

Although CBCT scanning causes low-dose radiation release, it is not a useful option for appreciating peri-implant structures due to continued radiation exposure on recurring scans on the same patient, a lack of detection of very thin bone layers, as well as beam hardening and scattering artifacts.[11–13]

Ultrasonography (USG), which was originally developed for the evaluation of soft tissues, is an imaging method with a portable device on which metals such as dental restorations and implants do not produ- ce artifacts. It is a noninvasive, cheap, painless, real-time, and radiation-free device. Although the structures behind the bone or completely within the bone cannot be visualized with USG, it has the ability to mea- sure the gingiva thickness in the oral cavity and show bone perforations. Additionally, the location, shape, and size of anatomical structures like the mental foramen can be easily determined by USG.[14–18]

Although it has been shown in previous studies that peri-implantitis can be evaluated using USG, no study has been found to evaluate technical errors (perforation of cortical plates, penetration of the mandibular canal and mental foremen, etc.) during implant placement. Our aim in this study was to investigate technical implant errors with CBCT and USG, and to evaluate the success of USG in demonstrating these complications.

METHOD

Study Design

Three freshly cut sheep heads were obtained from the national slaughterhouse for the study; however, two sheep mandibles were used because a fracture was detected in one of the sheep heads. A radiolo- gical examination was performed with both CBCT and USG before and after the implant placement. Implant planning was done using preopera- tive CBCT images, and the implants were placed in the diastema area, which was from the first incisor tooth to the first premolar in the sheep mandible.

Surgical Procedure

The surgical operations were all performed by YÖK, who has at least 10 years of experience in dental implant surgery using *Nucleoss T6 implant system* (Izmir, Turkey). Following the outline described in the manual for the implant system at specified sites, 10 implants (2 right, 3 left) were placed to represent normal placement (at the bone level and without the perforation of lingual or buccal bone, mandibular canal, or mental foramen) and 4 different complications crestal bone defect, cortical bone perforation, mental foramen perforation, and mandibular canal perforation (Fig 1).

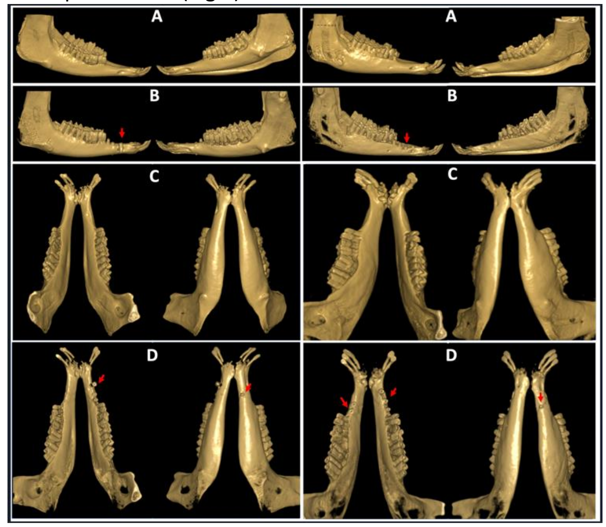

Figure 1(A-D): Preop and postop 3D CBCT images. A: Preop right and left images. B: Postop right and left images. Placed implants and complications can be seen. C: Preop occlusal and inferior view. D: Postop occlusal and inferior view. Crestal bone defect and cortical bone perforation can be seen.

Imaging procedures

CBCT scanning

CBCT procedures were performed with the same parameters before and after surgery. The images were taken with a *Newtom VGi evo* (Cefla, Imola, Italy, 110 kV, 15.3 mAs, slice thickness: 0.3, field of view: 240 × 190 mm). A secondary reconstruction with an axial thickness of 0.5 mm was performed parallel to the bases of the mandibles of sheep to be examined, followed by the primary reconstruction. Study reconstruction was obtained from both sheep heads with the same parameters. The mandibular canal was marked on the 0.1 mm thick panoramic sections for the right and left half-jaws. Then, the implant sites were examined in cross-sections with 0.5 mm intervals. The *QR-NNT version 11.5* (Quantitative Radiology) software program was used for analyses.

Ultrasound scanning

USG examinations were performed by a researcher (FC) with at least 10 years of experience in maxillofacial ultrasound. USG was applied using an *Aplio-300 device* (Toshiba Corporation, Tokyo, Japan), an 18 MHz hockey stick transducer. First, the probe was covered with gel and a sheath. During examinations, places where implants were placed were monitored on the horizontal and vertical planes by transoral approach. The visibility of normal placement implants and complications such as crestal bone defects, cortical bone perforation, mental foramen perforation, and mandibular canal perforation were evaluated by USG

RESULTS

In this study, the visibility of common complications in implant applications with CBCT and USG was evaluated. In two freshly cut sheep heads, 10 implants were placed, with 5 implants in each head.

CBCT was accepted as the gold standard in the evaluation of implant complications. The placement of all 10 implants in the bone, their positions, cortical bone perforations, and their relations with anatomical structures like the mandibular canal and mental foramen were clearly observed in both sheep heads with CBCT. The placement of the implants is generally seen in (Figure 2) in 0.5 mm axial sections and 1mm cross-sectional sections.

In the USG examination, similar findings were obtained in both sheep heads. The findings seen by USG in both sheep heads are summarized in Table 1. According to this, the implants placed in the normal position without complications could not be visualized by USG in both sheep heads. In the USG examination of alveolar bone, only the cortical surface of alveolar bone was seen as a hyperechoic line (Fig. 3A); the implant in the bone could not be seen in the USG, and it could only be visualized in the occlusal plane (Fig. 3B). Perforation areas of implants in the cortical bone were visualized by USG in both samples (Fig. 4). The mental foramen could be visualized preoperatively with USG, and the perforations caused by the implants in the mental foramen could also be visualized with USG (Fig. 5). In addition, positive findings were obtained by USG in a crestal bone defect (Fig. 6). Mandibular canal perforation could not be visualized by USG in both heads.

Table 1. Ultrasonographic visibility of implant complications and normal placement in both sheep heads.

Implant Placement Status	Ultrasound visibility	
	Sheep head 1	Sheep head 2
Normal placement	Invisible	Invisible
Cortical bone perforation	Visible	Visible
Mental foramen perforation	Visible	Visible
Mandibular canal perforation	Invisible	Invisible
Crestal bone defect	Visible	Visible

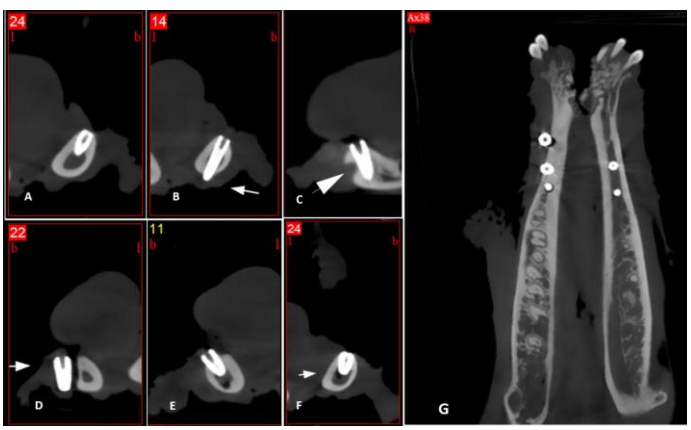

Figure 2 (A-G): Cross-sectional and axial CBCT images of implants. A: Normal placement, B: Cortical perforation, C: Mental foramen perforation, D: Advanced crestal bone loss, E: Crestal bone loss, F: Mandibular canal perforation, G: 0,5 mm axial view.

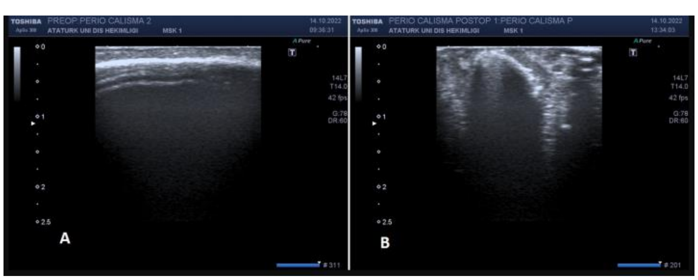

Figure 3(A-B): USG view of the normally placed intraosseous implant site. A: The implant in the bone is not visible, only the cortical surface of the alveolar bone was seen as a hyperechoic line. B: The upper edge of the implant is observed from the occlusal surface as hyperechoic on USG, comet tail artefact visible behind the metallic implant

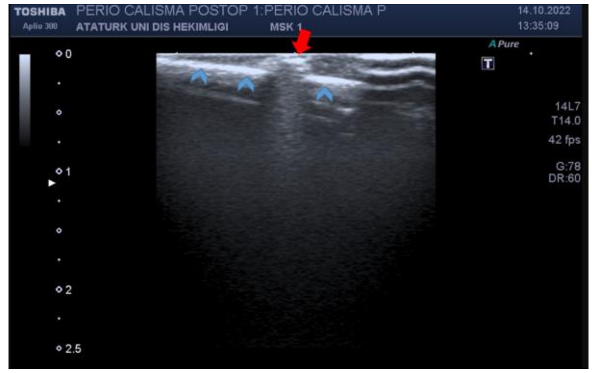

Figure 4: USG image of the implant causing the cortical perforation, blue arrowheads indicate mandibular cortical surface, red arrow indicates the tip of the implant at the perforation site. Reverberation artifact is observed behind the bone surface, and comet tail artifact is observed behind the implant.

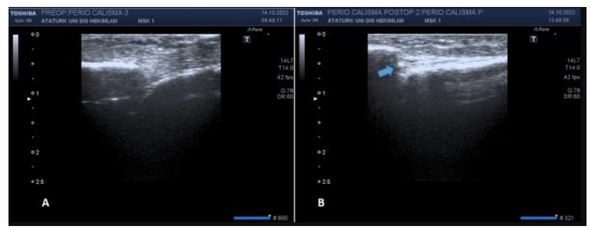

Figure 5 (A-B): USG image of the mental foramen before and after the implant. A: The mental foramen opening is observed as an interruption on the hyperechoic cortical bone surface, B: The implant that has perforated the mental foramen is observed in the foramen (blue arrow).

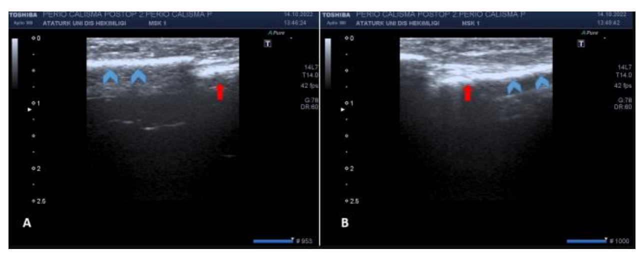

Figure 6 (A-B): Dislocated implants, blue arrowheads indicate mandibular cortical surface, red arrow indicates the tip of the implant. A: Advanced crestal bone loss. Placement outside the bone, B: Crestal bone loss

DISCUSSION

USG is becoming an increasingly popular method in the evaluation of implant success due to its ease of application, lack causing radiation exposure, and cost-effectiveness. In this study, the radiological evaluation of 6 different implant conditions artificially created in sheep mandible bones was compared with CBCT and USG.

Periodontal USG can be used in the evaluation of periodontal structures as a reliable, harmless, non-invasive and inexpensive method.[19] In recent studies, it has been seen that periodontal USG allows not only to evaluate the gingival thickness, also to examine many structures that cannot be evaluated by clinical examination.[20,21] Ultrasonic devices with small, high-frequency (40 MHz) transducers are used in periodontal USG. With this method, free gingival thickness, gingival sulcus depth, distance between gingival margin and alveolar bone crest, clinical and anatomical crown heights can be measured.[22] In addition, in-vitro studies have reported that it can be used in the evaluation of bone level and soft tissue thickness in implantology.[23,24]

In a study examining peri-implantitis by Bertram and Emshoff,[25] a probe with 12.5 MHz is used and in a study in which the height of alveolar bone around the teeth was compared with CBCT which was conducted on human cadavers by Chan et al.[26] a 14 MHz probe was used. In a study conducted by the same investigators and examining the peri-implant tissues of human cadavers, an ultrasound probe prototype with 25 MHz was used and the tissues around the implant were visualized.[27] In a clinical study conducted by Tattan et al.[28] the height and width of soft tissue level of crestal bone have been determined with a 24 MHz ultrasound probe. In our study, an ultrasound probe with 18 MHz was used and crestal bone loss around the implant, implant perforations that disturb mental foramen and cortical bone unity were detected. The use of higher-frequency probes increases image resolution, resulting in a clearer and more accurate topography of facial bones. With Ultra high ultrasound, a new USG technique developed recently, areas 1 cm from the surface can be examined with 30 µm resolution using frequencies up to 70 MHz.[29]

Probe sizes should also be smaller in order to obtain intraoral images more easily. Although it is easy to obtain images from buccal surfaces introrally with periodontal USG, the procedure becomes difficult due to the probe’s reach on lingual surfaces. It is impossible to obtain images from proximal surfaces with current technology.[20] Although we used sheep's heads in our study, considering the use of the probe in the human mouth, we took the image by keeping the cattle head in the rest position. Although we encountered some difficulties in imaging the perforation in the submandibular region, depending on the probe size and shape, we were able to obtain an image.

An uninterrupted, complete cortical bone structure is seen as a single line on USG, and structures inside the bone cannot be detected with USG. Situations in which the cortical bone gets thinner or perforation of the cortical bone emerges can be visualized by USG.[19] Similarly, irregularities on the bone surface, such as the foramen, can be visualized. In our previous study, the foramen mentale could be detected accurately by USG.[30] Similarly, in our study, implants that were completely embedded in the bone (the appropriately placed implant and the implant with mandibular canal perforation by being inside the bone) could not be detected by USG; foramen mentale and foramen mentale with the implant placed as perforated and lingual and crestal bone perforations could be detected using USG.

CBCT is frequently used to evaluate alveolar bone dimensions, and its accuracy has been achieved in thinner cadaver studies conducted, but it may be insufficient to detect bone thicknesses under 1mm due to the resolution limits.[31] The average anterior bone thickness of the maxillary teeth was between 0.5 and 0.7 mm, and the anterior wall thickness was less than 1 mm in approximately 90% of the teeth.[32] In a study in which 12 healthy implants were included and which was conducted by Veltri et al.[33] it was observed that the implant facial bone extended from the implant neck to the apical 3.8 mm, and the implant surface was not completely covered with bone in all of the implants. Another study that included 89 implants with peri-implantitis showed that 34% of the measured implant sites had uneven bone loss with greater resorption in the facial bone region.[34] In our study, all implants could be visualized with CBCT, but bone thickness under 1 mm could not be measured in the vestibule region. This situation supports previous studies, and the implant that is not at the bone level with artificial bone loss and the implant that has alveolar bone resorption in the vestibular region can be detected by USG. Bone measurement was not performed for this purpose in this study. As already mentioned, positive results may not be obtained in CBCT post-operative implant evaluations, especially in bone measurements, due to the artifacts. However, nowadays, with the development of various software programs and algorithms that minimize these metal-related disadvantages in CBCT, these disadvantages have begun to be overcome. Here comes the limitation of our work. Clinical studies using more samples and inclding measurements are needed in the future. However, with our findings, we can say that USG clearly shows complications such as cortical perforation, mental foramen perforation, crestal bone loss, and placement outside the bone. Our study may be a pioneer for future studies in this respect.

Especially in the diagnosis of peri-implantitis, 2D imaging methods such as panoramic radiography are frequently used, but even if bone losses in the interproximal regions are determined with these methods, bone losses in the vestibule and lingual region may not be detected due to the superposition of the implant. A similar problem is also valid for vestibule and lingual bone perforations caused by technical errors during surgery, revealing the necessity of applying CBCT imaging to detect these conditions. Although CBCT is a suitable bone evaluation method for implant planning, artifacts occur due to the metal of the implant, which creates problems in the evaluation of peri-implant tissues. Contrary to this, no such artifact is observed in USG, and no radiation exposure occurs. In addition, as in CBCT with USG, there is no need for a special room during image acquisition, and it is possible to quickly identify various implant complications and intervene in these complications by instantly taking images with USG after implant placement during the surgery. In this way, many complications can be addressed immediately without the need for a second operation.

The major limitation of the study was the small sample size. Another was that the anatomy of the sheep's head was not the same as the human head, even though it has similar features as a mammal.

CONCLUSION

In conclusion, USG is a useful imaging method that does not contain ionizing radiation and can be used to quickly detect technical errors such as cortical perforation, mental foramen perforation, crestal bone loss, and placement outside the bone that occur during implant surgery.

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Yazar Katkıları: Fikir- Y.Ö.K; Tasarım- Y.Ö.K., F.C.; Denetleme- Y.Ö.K., F.C.; Kaynaklar- Y.Ö.K., F.C.; Veri Toplanması ve/veya İşlemesi Y.Ö.K., F.C., H.Y., F.C.O.; Analiz ve/ veya Yorum- F.C.; Literatür Taraması- Y.Ö.K., F.C.; Yazıyı Yazan- Y.Ö.K., F.C.; Eleştirel İnceleme- Y.Ö.K., F.C., H.Y., F.C.O.
Çıkar Çatışması: Yazarlar, çıkar çatışması olmadığını beyan etmiştir.
Finansal Destek: Yazarlar, bu çalışma için finansal destek almadığını beyan etmiştir.

Ethics Committee Approval: Sheep heads were used in our study, and they were obtained from Republic of Turkey Meat and Milk Board. Because the animals were slaughtered for food consumption, not for a research, ethics committee approval was not required.
Peer-review: Externally peer-reviewed.
Author Contributions: Concept-Y.O.K; Design- Y.O.K., F.C.; Supervision- Y.O.K., F.C; Resources- Y.O.K., F.C.; Data Collection and/or Processing- Y.O.K., F.C., H.Y., F.C.O.; Analysis and/or Interpretation-F.C; Literature Search- Y.O.K., F.C; Writing Manuscript- Y.O.K., F.C; Critical Review- Y.O.K., F.C; Other- Y.O.K., F.C., H.Y., F.C.O

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