Med Ultrason 2018, Vol. 20, no. 4, 467-474
DOI: 10.11152/mu-1562

Comparison of Cone Beam Computed Tomography and ultrasonography with two types of probes in the detection of opaque and non-opaque foreign bodies

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Abstract

Aim: The aim of this study was to compare the diagnostic accuracy of intra-oral and extra-oral ultrasonographic (US) examinations performed with linear and convex probes in the detection of opaque and non-opaque foreign bodies (FBs) located in the maxillofacial area. **Materials and methods:** Thirteen different type of FBs were inserted into a sheep's head: a) on the external bone surface of mandible (between the mandibular corpus and masseter muscle), b) in the intrinsic muscular tissue (in the dorsum of the tongue) and c) in the hollow structures (into the maxillary sinus of the sheep's head). The FBs in muscle tissue were scanned intra-orally whereas FBs in bone external bone surface of mandible and in maxillary sinus were scanned both intra-orally and extra-orally. The sensitivity of cone beam computed tomography (CBCT) and US imaging methods in detection of FBs were compared for FBs on the bone surface and in the muscular tissue. **Results:** The intra-observer kappa coefficients provided identical values of 0.236 for the extra-oral convex probe, 0.461 for the intra-oral linear probe for overall FBs detection, which indicated notably poor to fair intra-observer agreement. The inter-observer agreement showed a poor agreement for the extra-oral use of linear probe (0.341 and 0.393) and extra-oral use of convex probe (0.319 and 0.335), However, a fair agreement was determined for use of probe intra-orally (0.530 and 0.534). Overall, the diagnostic accuracy of the CBCT was higher than the US regarding the visualization of FBs in the bone tissue. **Conclusion:** US with a linear probe should be the first choice for the detection of the low-radiodensity FBs, which are entrapped in the soft tissue. However, CBCT is a more sensitive technique for the visualization of FBs in air and bone tissue compared to the US, particularly for the diagnosis of high-radiodensity FBs.

Keywords: Foreign body; Ultrasonography; Cone Beam Computed Tomography

Introduction

A foreign body (FB) is an external object entrapped in the human body, which may enter into the head and neck region as a result of trauma, therapeutic interventions, motor vehicle accidents or gunshot wounds. Depending on the type of trauma, the composition and location of the foreign bodies (FBs) can vary considerably [1,2]. The most common FBs observed in the mandibular soft tissues are needles, bullet fragments, metal and glass particles [3]. An FB should be diagnosed and removed without delay in order to prevent complications such as pain, swelling, inflammation and infection [2].

Patient's medical history and clinical and radiological examination enable the diagnosis and localization of the FB [3]. The accurate localization of the FB is essential, in particular when the FB is in a critical location, (e.g. close

Received 19.04.2018 Accepted 28.10.2018
Med Ultrason
2018, Vol. 20, No 4, 467-474
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to a large vessel) and the operative removal has high risk for the patient [4].

Several methods can be used for the accurate localization of FBs in the soft and hard tissues including conventional radiography, ultrasonography (US), magnetic resonance imaging (MRI), cone beam computed tomography (CBCT) and computed tomography (CT) [2]. Among these techniques, conventional radiography is the primary imaging method used for the detection of FBs. However, the superimposition of tissues in the path of the X-ray beam and the overlooked radiolucent FBs in the soft tissue in some cases are the main drawbacks of this imaging method [5,6].

Because of the lower cost and lower radiation compared to the conventional CT, CBCT was preferred as the first-choice imaging technique in cases with suspected FBs in the maxillofacial region [7]. Kaviani et al [8] evaluated the diagnostic reliability of CT and CBCT in the identification of FBs such as metal, tooth, wood, plastic, glass stone and graphite. They reported that apart from wood, all other FBs were detectable with both CT and CBCT imaging.

It was reported that US might be useful for the localization of the superficial FBs, particularly in the detection of radiolucent FBs. However, it may be unsuitable for those FBs which are in deep regions and inside the air-filled cavities [1,9]. In a recent study, Davis et al [10] published a systemic review and meta-analysis focused on the detection of FBs with US. They concluded that US could be a useful diagnostic tool in the evaluation of FBs located in the skin and soft tissues. Panigrahi et al [11] reported that US was a useful tool for the detection of the superficial and deep (maximum 3 cm) low-radiopaque FBs like wood, sand and fiber plastic. Blankenship et al [12] demonstrated that wooden objects in the air-filled cavities (e.g. maxillary sinus) or on the bone surface could not be detected with US. In addition, they demonstrated that US was a reliable method for the detection of FBs entrapped in the soft tissue and CT was the most efficient method for the detection of FBs entrapped in the air-filled cavities.

Shokri et al [2] compared the sensitivity of CBCT, MRI and US in the detection of FBs in the sheep's head and found that CBCT had the highest sensitivity (79.19 %), followed by US (33.33 %) and MRI (20.83 %). While wood is the most difficult FB to be detected with any imaging method, stone and barium glass were the most easily visualized FBs. Javadrashid et al [7] compared different imaging methods regarding the detection of FBs, which were inserted in the extraocular space of a sheep's head. Results revealed that all FBs, except wood, were best visualized in the CT and CBCT images with almost the same sensitivity. Wood was best visualized in the MRI images but only if it was larger than 2 mm.

In several studies, the sensitivity of US with the single linear probe was evaluated for the visualization of FB [1,6]. In these studies the probe was used extra-orally. Only Aras et al [1] used intra-oral linear probes for the detection of FBs.

The aim of this study was to compare the diagnostic accuracy of intra-oral and extra-oral US examinations performed with linear and convex probes and CBCT in the detection of opaque and non-opaque FBs implanted in a sheep's head.

Material and methods

In this study 13 different FBs were used. All FBs were calibrated to a dimension of approximative 1x1x0.1 cm. FBs were wood, chicken bone fragment, acrylic (Vertex, Netherlands), plastic, fish bone, dental composite (Clearfil Majesty, Kuraray, Germany), glass, root, injector needle, stone, tooth enamel, amalgam (Avalloy, Cavex, Holland), orthodontic wire (Medifarm, Turkey). Like previous studies [1,3], a Multislice Computed Tomography (MSCT) scanner was used as a benchmark for the evaluation of the radiopacity of the FBs. To ensure the standardization in the CT imaging, the sheep's head was fixed during the insertion of FBs and CT scanning.

MSCT was obtained with a non-contrast low-dose CT (Philips Brilliance iCT, 256 slice multidetector CT). Imaging parameters were; 590 mAs, 120 kV, 1 mm slice selection with an anisotropic voxel size 0.625x1.5x1.0 mm, 512x512x399 image matrix and pitch 1. The HU-value at the center of each sample was measured with the dedicated software of MSCT. The materials used with HU values were listed (Table I). In this study, only one specimen (sheep's head) was used. The specimen was used one day after the animal was slaughtered.

FBs were placed in various locations: a) *on the bone surface:* in the submandibular fossa between the mandibular corpus and muscle. An incision was made with a scalpel, a pocket was prepared within the muscle and the FB was placed vertically on the bone's surface in the submandibular fossa; b) *in the muscular tissue:* in one side of the dorsal region of the tongue with a scalpel. The FBs were embedded 5 mm below the mucosa following the incision; c) *in the hollow structures:* into the maxillary sinus of the sheep's head. A triangular window was opened in the crestal ridge of the maxilla with a sharp osteotome and the FB was placed directly into the sinus. FBs were inserted into the maxillary sinus cavity with the surrounding soft tissue to mimic the infectious tissue, which usually emerges around FB. FBs were retained in

Table I. Radiodensity of tested foreign bodies in CT scans

Foreign Body	HU value in MSCT	Reference	HU value in MSCT
Wood	60-140	Air (maxillary sinus)	0
Chicken bone fragment	95-135	Muscle	80-165
Acrylic	100-160	Cortical Bone	820-990
Plastic	105-160		
Fish Bone	125-156		
Dental Composite	410-920		
Glass	620-1800		
Root	1850-2910		
Injector needle	3800-6560		
Stone	2700-3100		
Tooth enamel	2800-3200		
Amalgam	2900-3130		
Orthodontic wire	4100-7330		

FBs – Foreign Bodies; CT – Computed Tomography; HU – Hounsfield Unit; MSCT – Multislice Computed Tomography

Fig 1. Scanning of the sheep head using: a) linear probe in the dorsum of the tongue intra-orally; b) convex probe in the maxillary sinus extra-orally; c) linear probe in the maxillary sinus intra-orally; d) convex probe in the in the submandibular region extra-orally; e) linear probe in the in the submandibular region intra-orally.

the maxillary sinus under the mucosal layer (close to the insertion site). The pocket was closed before the examination (fig 1).

The imaging methods

A US device (ProSound Alpha 6, Hitachi Aloka Medical Ltd., Tokyo, Japan) with a convex 3-5.71 MHz and a linear probes 5-13.3 MHz was used. All FBs were scanned both intra-orally and extra-orally. The extra-oral scanning was carried out with the convex and linear probes and the intra-oral scanning was performed only with a linear probe.

One independent investigator (C.G.) inserted all FBs and another two observers (S.K. and K.O.) performed all US scanning and evaluations. All observers were dentomaxillofacial radiologists with 8 years and 15 years of experience in using US and CBCT. The two observers performed two separate US sessions independently. The observers carried out the examination twice in 1-month intervals after the first US scanning. The same sheep head and same FBs were used during both US scanning. The head was placed into a clamp in order to ensure the same position achieved during each scanning. The observers

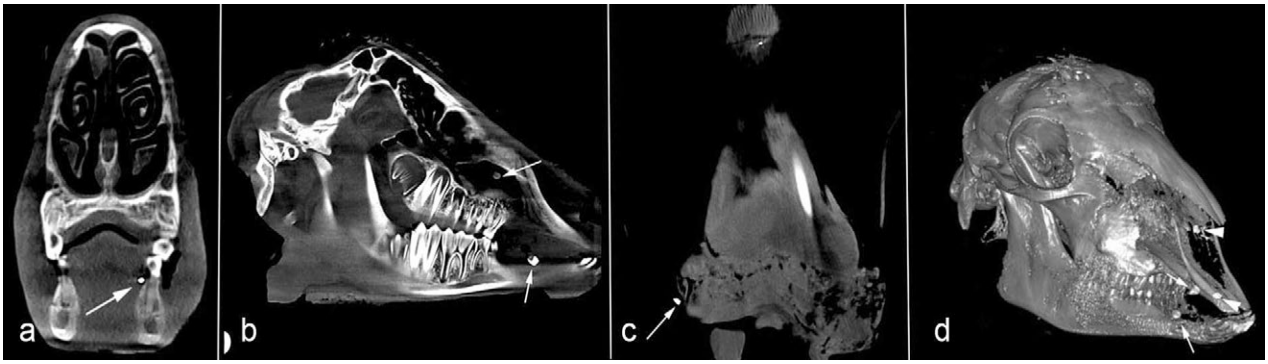

Fig 2. a) The coronal CBCT image showing the composite (arrow); b) the sagittal CBCT image showing glass in the air cavity (upper arrow) and amalgam in the dorsum of the tongue (below arrow); c) the axial CBCT image showing amalgam in the submandibular fossa; d) 3D CBCT reconstruction showing amalgam in the maxillary sinus (upper arrowhead), stone in the dorsum of the tongue (arrowhead and upper arrow), tooth enamel (below arrow).

were free to position the probe during the obtainment of the images.

CBCT images were taken with a Planmeca Promax 3D Max CBCT (Planmeca Oy, Helsinki, Finland) (fig 2). During CBCT imaging, to ensure the standardization again, the sheep's head was fixed and its position was preserved during FB insertion. The exposure parameter settings included: 96 kVp, 12 mA, 0.200 mm^3 voxel. The exposure time was 18 seconds and a 360 degree-rotation was selected. After the scanning, all constructions and evaluations were performed on a 21.3-inch flat-panel color-active matrix TFT medical display (NEC MultiSync MD215MG, München, Germany) with a resolution of 2048x2560 at 75 Hz and 0.17 mm dot pitch operated at 11.9 bits.

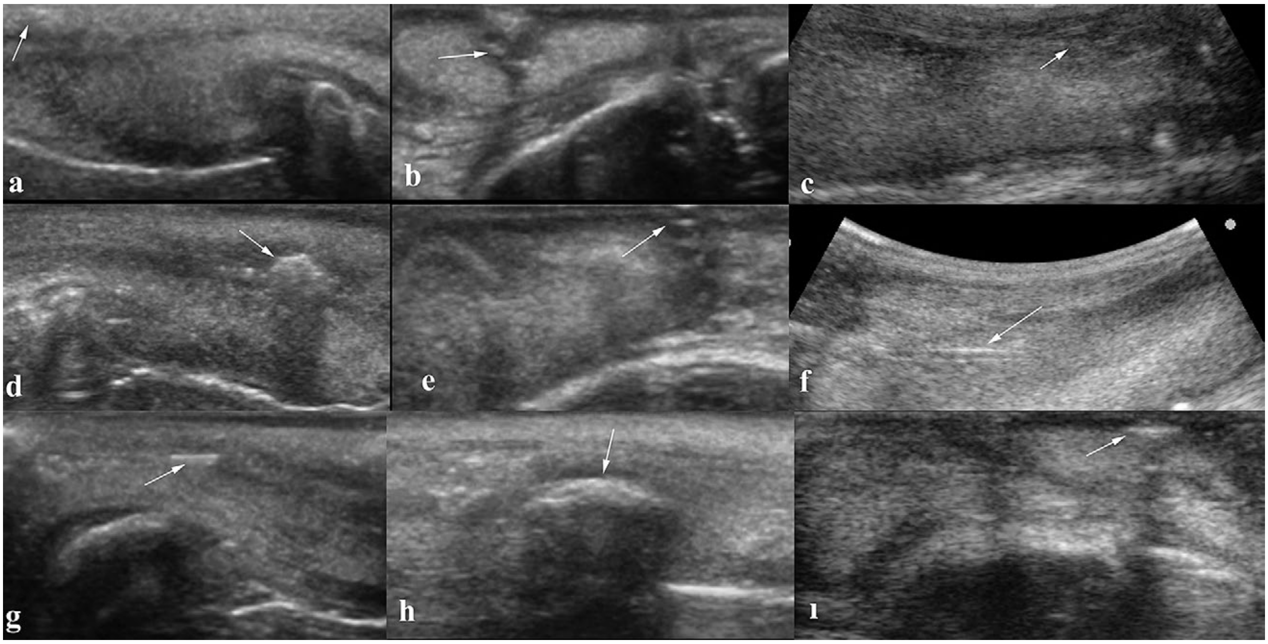

Fig 3. US images showing a) the dorsum of the tongue , with wood as a foreign body (arrow) using intra-oral linear probe, b) extra-oral linear probe and c) extra-oral convex probe; d) scanning of amalgam with an intra-oral linear probe (arrow), e) extra-oral linear probe (arrow) and f) extra-oral convex probe (arrow); g) scanning of injector needle with an intra-oral linear probe (arrow); h) scanning of a stone with acoustic shadowing with an intra-oral linear probe (arrow); i) scanning of tooth enamel with an intra-oral linear probe (arrow).

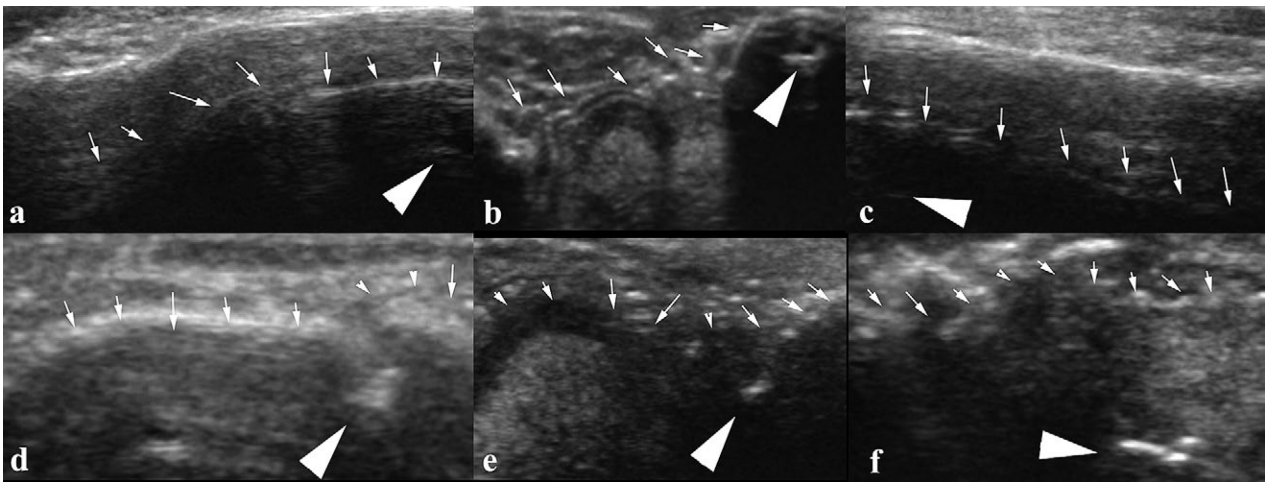

Fig 4. US images of the maxillary sinus (multiple arrows) with a) acrylic as a foreign body with an intra-oral linear probe; b) glass, intra-oral linear probe; c) wood, intra-oral linear probe; d) stone, intra-oral linear probe; e) plastic, intra-oral linear probe and f) s injector needle with an intra-oral linear probe (arrowheads).

Before each US scanning session the independent investigator (C.G.) was free “to place or not to place the FB”. The observers performed USs scanned 26 times in the same region, mentioning the presence/absence and the type of FB.

Totally 6 CBCT were performed with the same voxel and scanning parameters. The independent investigator repeated the evaluation for each region 6 times and decided on the presence of FB and recorded his decision as the gold standard for the study.

Image analysis

Before US and CBCT evaluations, both observers were previously trained for the appropriate use of the software in both US and CBCT in a special session. Moreover, 10 CBCT images and 10 US examinations with FB were used to define and calibrate the FB. In all imaging methods, a three-point scale was used to assess each FB’s visibility (fig 3, fig 4): (0) not visible; (1) probably visible; (2) definitively visible [1].

The examiner reliability and statistical analysis

Kappa coefficients were calculated to assess both intra- and inter-observer agreements for each image set. Kappa values were interpreted according to the guidelines of Landis and Koch (adapted by Altman) [13]: $\kappa \leq 0.20$ poor; $\kappa = 0.21–0.40$ fair; $\kappa = 0.41–0.60$ moderate; $\kappa = 0.61–0.80$ good and $\kappa = 0.81–1.00$ very good. The scores obtained from (1) the intra-oral use of a linear probe; (2) extra-oral use of a linear probe; (3) extra-orally use of convex probe and (4) CBCT images were compared with the gold standard. Statistical analyses were performed for each image type, observer, and reading using the Bonferroni-Dunn and Kruskal-Wallis H tests to determine the differences between the groups. For all analysis, $p<0.05$ was considered as statistically significant.

Results

Thirteen FBs were used for the evaluation the detection capability of US and CBCT imaging. In US all FBs were echogenic, 6 of them (46.1%) had acoustic shadowing and 7 (53.9%) a hypoechoic halo. The chicken bone fragment, root, stone, tooth enamel, amalgam, orthodontic wire had an acoustic shadowing and the rest had a hypoechoic halo.

The intra-observer kappa coefficients calculated for each observer regarding the image type are detailed in Table II. The highest kappa value in the intra-observer agreement was obtained with CBCT images by both observers. The intra-observer kappa coefficients provided identical values of 0.236 for the extra-oral use of the convex probe, 0.461 for the intra-oral use of the linear probe, which indicated notably poor to fair intra-observer agreement. However, CBCT images showed an agreement of 0.676 to 0.719 indicating a good intra-observer agreement.

The inter-observer kappa coefficients are summarized in Table III. A good inter-observer agreement was achieved in the CBCT images with kappa values between 0.726 and 0.745. In contrast to this, a poor inter-observer agreement emerged for the extra-orally use of the linear probe (0.341 and 0.393) and extra-orally use of the convex probe (0.319 and 0.335). However, a fair agree-

Table II. Intra-observer agreement calculated for each observer by the image type of all foreign bodies

	Observer 1			Observer 2			Total		
	Kappa	**SE**	**p-value**	**Kappa**	**SE**	**p-value**	**Kappa**	**SE**	**p-value**
US Linear probe intra-orally	0.383	0.060	0.000	0.461	0.059	0.000	0.422	0.059	
US Linear probe extra-orally	0.326	0.062	0.000	0.315	0.064	0.011	0.320	0.063	<0.05
US Convex probe extra-orally	0.236	0.074	0.000	0.290	0.078	0.001	0.263	0.076	
CBCT	0.676	0.024	0.000	0.719	0.028	0.000	0.697	0.026	

SE – Standard Error; US – Ultrasonography; CBCT – Cone Beam Computed Tomography

Table III. Inter-observer kappa coefficients among observers for first and second readings

	First Reading Obs. 1 – Obs. 2			Second Reading Obs. 1 – Obs. 2			Total		
	Kappa	**SE**	**p-value**	**Kappa**	**SE**	**p-value**	**Kappa**	**SE**	**p-value**
US Linear probe intra-orally	0.530	0.042	0.000	0.534	0.046	0.000	0.532	0.044	
US Linear probe extra-orally	0.393	0.058	0.000	0.341	0.061	0.000	0.367	0.059	<0.05
US Convex probe extra-orally	0.319	0.049	0.000	0.335	0.064	0.000	0.327	0.056	
CBCT	0.726	0.026	0.000	0.745	0.028	0.000	0.735	0.027	

SE – Standard Error; US – Ultrasonography; CBCT – Cone Beam Computed Tomography; Obs – Observer ment was determined between the intra-oral linear probes (0.530 and 0.534) in the USG.

The comparisons of the imaging methods were also evaluated using the Bonferroni/Dunn and Kruskal-Wallis H tests. The results showed that the intra-oral use of linear probe examinations were statistically different from other US imaging methods. ($p <0.05$)

The sensitivity of the four imaging methods for the detection of FBs and their sensitivity, specificity, positive and negative predictive values for each region and FB were calculated (see supplementary file on the journal site). The highest sensitivity was obtained for wood and chicken bone fragments in the muscle imaging with an intra-oral use of the US probe, while CBCT imaging had the highest sensitivity for the orthodontic wire, amalgam and stone. Low-density materials could be better detected with an intra-oral use of the probe.

Regarding the FBs inserted in the bone, the highest sensitivity was for glass, root and injector needle was obtained with the intra-oral use of the US probe. CBCT had the highest sensitivity for the tooth enamel, orthodontic wire, amalgam and stone inserted in the bone. Overall, the diagnostic accuracy of the CBCT was higher than US regarding the visualization of FBs in the bone tissue.

Regarding the visualization of FBs in an air cavity, US provided the highest sensitivity with the intra-oral use rather than use of extra-oral use of linear probes.

Discussions

The detection of a FB and its accurate localization are important for its safe removal. The clinicians have to choose the most efficient imaging method. The quality of the visualization in different imaging methods depends on the composition of FB. While a non-opaque FB might be overlooked in one technique, another one might be successful in the detection [14].

Apart from the limitation due to operator-dependence, the high-resolution US is a safe, inexpensive, non-ionizing, portable and easily available imaging method for the diagnosis of FBs [15]. The performance and imaging quality of US are highly affected by the characteristics and the structure of the probe. Regarding the imaging of the head and neck region, the linear probes with rectangular and flat surfaces are most appropriate for examination and are useful for the imaging of the shallow structures and small parts [16]. The convex probes enable a trapezoidal view field due to the divergence of the ultrasound beam with an increasing depth. This provides a broader field of view but has a decreased line density at depth and a reduced lateral resolution [17,18].

The investigated FB materials are typically common in the head and neck. Entrapped FBs may be encountered in any of the following three different areas of the human body: air-filled cavity, soft tissue or between bone and muscle [3]. Therefore, we used in our study the maxillary sinus, tongue and submandibular fossa, which represented these three areas.

One of the reasons for the conflicting findings in various studies may be the different dimensions of the FBs. The size of FBs used in our study was not significantly smaller compared to the previous studies. Nevertheless, some of them were not well visualized, especially in US imaging. The other reason was that many studies on FB detection have been carried out in a homogenous background such as cadaver thighs and cubes of meat that require the identification of only a single tissue interface. A sheep's head represents multiple tissue interfaces (e.g. muscle, bone, fat, tendon and bone). An FB has one more interface to detect. Also, because of the close proximity, one interface may actually distort or obliterate a second interface with its acoustic shadow.

In the CT examination, Hounsfield Unit (HU) is proportional to the degree of the X-ray attenuation and it is allocated to each pixel to show the image that captures the density of the tissue. In CBCT, the degree of X-ray attenuation is shown by a grayscale (voxel value). Although CBCT manufacturers and software providers introduced grayscales such as the HU, it is critical to know that these measurements are not a correct HU [5]. The radiopacity was measured in HU using a CT-scanner to determine the level of the radiopacity of the materials tested in this study. However, further studies should be made especially the comparison of gray levels that is produced by CBCT and HU using a CT-scanner on the detection of FBs.

A recent systemic review concluded that US could be a powerful tool for the detection of FBs in the skin and soft tissues [10]. While Aras et al [1] investigated FBs with US using a single linear probe, Valizadeh et al [6] examined FBs with US using linear probes in different set-ups for different FBs. It was stated that US could detect and localize superficial FBs with low radiopacity in the tissues but not in the air cavities. However, in all these studies, the probe was used extra-orally but in our study we used 2 probes and 3 acquisition modes as extra-oral and intra-oral measurements. In contrast to previous studies, our results showed that FBs in air cavities could also be detected with the intra-oral use of linear probes.

The results of the current study evidenced that FBs with a higher density (e.g. amalgam, orthodontic wire and injector needle) had higher quality images in CBCT. The objects with a lower density such as wood were sufficiently visualized with any of these two methods. However, considering the examination of the muscle tissue, FBs with low radiopacity could be better detected with US compared to CBCT.

The US images are corrupted by an important noise, often called speckle, and exhibit imaging artifacts such as signal attenuation and acoustic shadows. The high dynamic range includes a wide range of echogenicity from weak to strong, which enables the observation in many details [19,20]. Hence, the intra-oral use of linear probes may assure a strong echogenicity for the distinguishing of different FBs. In other words, intra-oral use of probes may be recommended for a better visualization of the FBs.

One of the limitations of this study was that only one sheep's head was used for the examination of different procedures. Although the US examination was carried out in two sessions with two observers, additional specimens, additional observers with different experience levels are required in order to overcome the US observer-dependent differences.

In our study FBs were placed into the maxillary sinus, being surrounded by soft tissues to mimics the infectious tissue around the FB (maxillary sinusitis) but we did not test the visualization of the FB in the air-filled maxillary sinus. Therefore, no definitive conclusion could be made regarding the visualization of an FB in a healthy sinus. Further studies should be conducted to clarify this issue.

In conclusion, FBs with high radiopacity were better visualized with CBCT compared to US. However, US with a linear probe should be the first choice for the detection of the low-radiodensity foreign bodies, which are entrapped in the soft tissue. The intra-oral use of linear probes may achieve a strong echogenicity for the distinguishing of different FBs and can be recommended for FBs that are located intra-oral tissues.

Conflict of interest: none

Acknowlegments: The authors would like to thank Ministry of Health of Turkey, particularly Dr. Nafiz Körez Sincan Goverment Hospital for allowing and providing US machine.

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