Effects of Image Postprocessing in Digital Radiography to Detect Wooden, Soft Tissue Foreign Bodies

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Purpose To investigate the effects of image postprocessing functions (ie, edge enhancement, noise reduction, and sharpening) that are available on digital radiography systems, including computed radiography (CR) and direct digital radiography (DDR), for detection of wooden, soft tissue foreign bodies.

Methods Dorsoplantar and lateral porcine foot radiographs with 4 lengths of wooden foreign bodies (no foreign bodies, 2 mm, 5 mm, and 10 mm) placed 1 mm (superficial) and 1 cm (deep) below the skin were acquired by CR and DDR systems using 10 exposure factors. Images were postprocessed to produce 960 images, including original CR, original DDR, sharpened CR, sharpened DDR, edge-enhanced DDR, and noised-reduced DDR images. Contrast-to-noise ratios (CNR) were used for objective assessments of foreign body visibility on the images. Six Australian radiologic technologists were recruited to review selected images. Australia allows radiologic technologists to provide initial comments on plain radiographs with the supervision of a radiologist. Technologists rated the visibility of foreign bodies using a 4-point scale to determine diagnostic performances of different image receptor and postprocessing types. Means, standard deviations, analyses of variance, and intraclass correlation coefficients were calculated for statistical analyses.

Results Among the CR and DDR images with and without postprocessing, the edge-enhanced DDR images had the highest overall mean CNR value (3.39, $P = .003$) and sensitivity (35.13%). The sensitivity of the edge-enhanced DDR images for detecting the 10 mm foreign body was 43.33%.

Discussion Edge-enhanced DDR can be considered an additional tool for suspected wooden, soft tissue foreign body diagnoses in rural areas where digital radiography is the only available imaging modality. This would allow some patients in rural areas to avoid long-distance travel to access sonography or computed tomography to detect foreign bodies, which could minimize emotional, financial, and social costs.

Conclusion This study shows that the image postprocessing function of the DDR system can detect wooden, soft tissue foreign bodies. Edge enhancement, specifically, can improve wooden, soft tissue foreign body detection, especially for large foreign bodies ($\geq$ 10 mm).

Keywords *digital radiography, edge enhancement, foreign body, image postprocessing, noise reduction, sharpening*

Foreign bodies present in soft tissue wounds are a common medical condition, and the most common type of foreign body found in soft tissue is wood.[1-3] Retained foreign bodies in soft tissue should be removed within 24 hours after injury to achieve optimal treatment outcomes such as reduced inflammation, induration, and scarring.[1] If foreign bodies are undetected and retained, adverse consequences might occur[4]:

- continued pain
- extensive surgery
- increased medical expense
- malpractice lawsuits against medical practitioners
- multiple clinical center visits
- tissue infection

Approximately one-third of emergency department malpractice claims are related to retained foreign bodies in soft tissue.[1] Therefore, diagnostic imaging pathways have been established for foreign body diagnosis.[2] For example, the Government of Western Australia's diagnostic imaging pathway for suspected foreign bodies suggests that sonography and computed tomography (CT) be used to detect radiolucent foreign bodies, such as wood, that are superficial or deeply embedded, respectively. Wooden foreign bodies cannot be detected on radiographs because screen-film radiography has low-contrast resolution, and visualization of low-contrast objects like wooden foreign bodies requires high-contrast resolution.[2,5]

However, in some instances (eg, rural areas), plain radiography is the only available imaging modality. Patients in rural areas who have wooden, soft tissue foreign bodies and need sonography or CT are required to travel long distances to regional or country hospitals. The long-distance travel might delay treatment and increase emotional, financial, and social costs.[6] Another issue affecting rural areas is a shortage of radiologists, which can cause further delays in diagnosis, and hence, treatment. Some countries, such as Australia and the United Kingdom, allow radiologic technologists to provide initial comments on plain radiographs with the supervision of a radiologist.[7,8] This initial commenting arrangement enables the radiologists to prioritize reporting of their cases so that the patients can receive diagnostic reports and necessary treatments promptly.[8]

The emergence of digital radiography with superior contrast resolution, however, has formed a new basis for reinvestigating the role of widely available plain radiography in wooden, soft tissue foreign body detection. A recent experimental study investigated the diagnostic performance of direct digital radiography (DDR) to detect wooden, soft tissue foreign bodies in porcine feet. Although the results showed that the DDR had an overall sensitivity of 4.17%, the researchers did not investigate potential effects of image postprocessing on foreign body detection but did suggest further research in this area.[9]

Several studies have explored the effects of image postprocessing functions used in digital radiography, including computed radiography (CR) and DDR, in other areas.[10-12] The edge-enhancement image postprocessing function appeared particularly useful for evaluations of central venous catheters and esophageal tubes on bedside chest radiographs.[10] The noise-reduction function was found to improve radiologists' perceptions on low-dose pediatric pelvic image quality.[11] For dental radiography, the sharpening function was identified as the most effective approach to increase diagnostic accuracy for caries.[12] However, the effects of image postprocessing in digital radiography to detect soft tissue foreign bodies have not been investigated yet.[9,13-15] Based on previous studies' findings,[10-12] image postprocessing should have positive effects on the detection of wooden, soft tissue foreign bodies. The purpose of this study is to investigate the effects of the image postprocessing functions, including edge enhancement, noise reduction, and sharpening, available for digital radiography (ie, CR and DDR) systems to detect wooden, soft tissue foreign bodies.

Methods

This experimental study used methods like those of Mercado and Hayre.[9] A 19-gauge needle was used to make a superficial or deep puncture wound (tunnel) underwater in the soft tissue of 8 completely thawed porcine feet, purchased from a supermarket. Each tunnel was parallel to the second digit's long axis on every foot, adjacent to the distal interphalangeal joint, and measured 1 mm (superficial) or 1 cm (deep) from the surface of the skin. **Figure 1** shows a representative puncture wound location. For 6 of the 8 feet, water-soaked toothpicks (2 mm diameter) with lengths of 2 mm, 5 mm, or 10 mm were inserted manually into each tunnel to 1 mm (superficial) or 1 cm (deep) from the surface of the skin. This resulted in 6 experimental

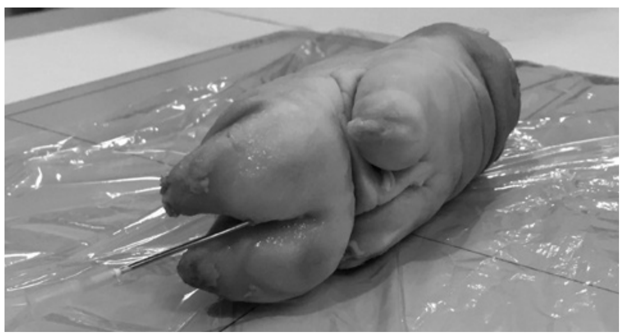

Figure 1. *Photograph demonstrating needle's position in the porcine foot. Image courtesy of the authors.*

models, with 1 wooden, soft tissue foreign body of different lengths and locations:

- 2 mm long foreign body, 1 mm from the surface of the skin
- 2 mm long foreign body, 1 cm from the surface of the skin
- 5 mm long foreign body, 1 mm from the surface of the skin
- 5 mm long foreign body, 1 cm from the surface f the skin
- 10 mm long foreign body, 1 mm from the surface of the skin
- 10 mm long foreign body, 1 cm from the surface of the skin

Two models without a foreign body acted as control specimens. The porcine feet were selected to mimic human feet because their bony and soft tissue structures are like humans'.[9] The university's Human Research Ethics Committee's approval (HRE2020-0310) was obtained on June 11, 2020, and the study was conducted the same year.

Image Acquisition

A RADspeed general radiographic system (Shimadzu Corporation) with a total x-ray beam filtration of 4 mm aluminum, a CR system (CR 30-X; Agfa HealthCare NV) and a DDR system (CXDI-70C; Canon Medical Systems Corporation) were used to acquire original (ie, without image postprocessing) dorsoplantar and lateral images of the 8 porcine feet. In the dorsoplantar images with deeply embedded foreign bodies and the lateral images with superficial foreign bodies, the foreign bodies overlapped with the phalanges; in other images, the foreign bodies were free from superimposition.[2] **Tables 1** and **2** show specifications[16-19] and image acquisition parameters[2,9,13,20] of the CR and DDR systems. Regular quality assurance checks were completed for the CR and DDR systems by their vendors.

The image postprocessing functions edge enhancement, noise reduction, and sharpening, which were employed in previous studies, were used to enhance the original DDR images.[10-12] Only the sharpening function was applied to the original CR images because the other postprocessing functions were not available on the CR system.[17] A maximum level of enhancement was selected for each postprocessing type.[17,19] A total of

Table 1

Specifications of Computed Radiography and Direct Digital Radiography Systems[13-16]

Specifications	Computed radiography system (CR 30-X)	Direct digital radiography system (CXDI-70C)
Image receptor size, cm	35 × 43	35 × 43
Pixel matrix	3480 × 4248	2800 × 3408
Pixel size, µm	100	125

Table 2

Porcine Foot Image Acquisition Parameters

Parameters	Settings
Exposure factors, kV / mAs[a]	40 / 3.2 45 / 3.2 50 / 2 50 / 3.2 55 / 2 55 / 3.2 60 / 1.6 60 / 2 60 / 3.2 63 / 1.6
Source-to-image receptor distance, cm[b]	100
Central ray[b]	Directed to the center of the foot perpendicular to the image receptor
Collimation[b]	Including skin margins
Focal spot size, mm[b]	0.6
Foreign body marker	2 markers (perpendicular to each other) placed on the image receptor to indicate the specific location of the puncture wound for facilitating subsequent data analysis
Image processing algorithm[b]	Foot

[a] *Based on similar studies.*[2,6,10]

[b] *Based on human foot x-ray examination.*[17]

960 images were acquired: 4 foreign body lengths (ie, no foreign body, 2 mm, 5 mm, and 10 mm) × 2 foreign body locations (superficial and deep) × 2 projections (dorsoplantar and lateral) × 10 exposure factors × 6 image receptor and postprocessing types (original CR, original DDR, sharpened CR, sharpened DDR, edge-enhanced DDR, and noised-reduced DDR). Manual exposures were used in this study, and the 10 exposure factors were selected based on similar studies.[2,9,13]

Image Analysis

The image analysis was divided into 2 parts based on similar studies.[2,9,13] Part 1 involved an export of all 960 images as DICOM files to a workstation with an open-source image processing program (ImageJ 1.51a; National Institutes of Health) to measure mean pixel values (MPVs) of the region of interest (ie, foreign body) and 3 background areas adjacent to the foreign body. Standard deviations of the pixel values (PVSDs) of the background areas also were measured (see **Figure 2**). These measured values were used to calculate the contrast-to-noise ratio (CNR) using the following equation[2,21]:

$$\frac{(\text{MPV}_{\text{Foreign bodies}} - \text{Average MPV}_{\text{Background}})}{\text{Average PVSD}_{\text{Background}}}$$

The CNR was used as an objective assessment of foreign body visibility in the images. A greater CNR value indicated better foreign body visualization, positively affecting its detection.[2,21]

For part 2 of the image analysis, 6 Australian radiologic technologists who were registered with the Medical Radiation Practice Board of Australia of the Australian Health Practitioner Regulation Agency and had 1 to 3 years of plain radiography experience and no visual impairments were recruited. In accordance with their scope of practice, they were asked to provide comments on a total of 198 images selected from the 960 images and rate the foreign body visibility using a 4-point scale (1 = not visible; 2 = poor visibility; 3 = good visibility; 4 = excellent visibility).[2,9] For image selection, the 960 images were first categorized into 96 groups based on the 4 foreign body lengths,

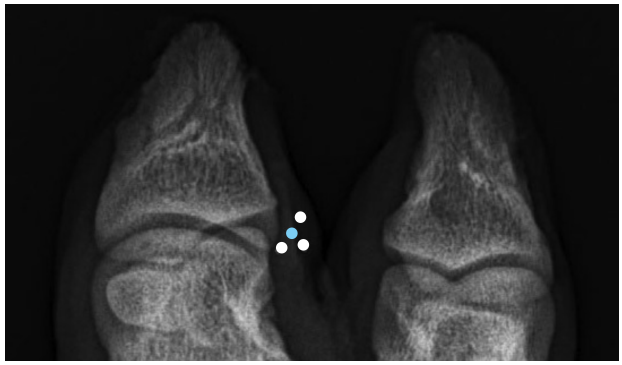

Figure 2. *Locations of the region of interest (central circle in blue) and the 3 background areas (peripheral circles in white) on a cropped dorsoplantar image with a superficial 10 mm foreign body for the pixel-value measurement. There are approximately 20 pixels in each circle. Image courtesy of the authors.*

2 locations, 2 projections, and 6 image receptor and postprocessing types. One image was selected randomly from each group (96 images selected in total). Previously unselected images were grouped together as a single pool, and 90 extra images were drawn randomly from this pool. These 2 selection processes yielded 186 images. In addition, 12 images were selected randomly from this pool of 186 images and added back in as duplications for determination of test-retest reliability, yielding a total of 198 images.[2,13]

The 198 images were displayed in random order on a 68.6 cm (27 in), consumer-grade, LED monitor (Asus PG279Q; ASUSTek Computer Inc) with 2560 × 1440 pixels, 0.23 mm pixel pitch, and 350 cd/m^2 maximum luminance via the ImageJ program.[2,22] A consumer-grade LED monitor without DICOM grayscale standard-display function calibration was used because previous studies found that its use did not have significant effects on image quality perception and diagnostic performance.[23,24] All observers completed the image interpretation independently with matching viewing conditions per the established technical standard: same workstation, monitor, and setting (ie, medical imaging laboratory with 32 lux ambient lighting level); optimal air flow, temperature, and humidity; and minimal noise.[25] Although all observers received formal image-interpretation education through their previous undergraduate study, specific instructions for completion of this subjective image analysis (ie, how to use the 4-point scale to rate foreign body visibility and record ratings on the data collection form) were given to them. They were blinded to all image acquisition settings. Image magnification and windowing were allowed.[9,10,13,15] Informed consent was obtained from each observer before image analysis.

Statistical Analysis

The 6 image receptor and postprocessing types were used to categorize the CNR data. Mean and standard deviation were calculated for each category, and the mean values were compared through 1-way analysis of variance to determine effects of the image receptor and postprocessing types on foreign body visibility. To identify their influences on foreign body visibility, these data were categorized further by projection type, foreign body location, and exposure factor.[2] Observer's ratings on foreign body visibility were grouped first by image receptor and postprocessing types and then by foreign body lengths. A rating of 1 (not visible) or 2 (poor visibility) indicated absence of a foreign body, and 3 (good visibility) or 4 (excellent visibility) represented the presence of a foreign body. The results were compared with the true presence or absence of a foreign body to determine the number of true positives, true negatives, false positives, and false negatives made by each observer for every group and subgroup. Mean sensitivity, specificity, and accuracy, and their standard deviations were calculated based on the number of true positives, true negatives, false positives, and false negatives.[9] The intraclass correlation coefficient (ICC) was used to determine the test-retest and interobserver reliabilities.[2,13] The ICC values, < 0.40, 0.40-0.59, 0.60-0.74 and 0.75-1.00 indicated poor, fair, good and excellent reliabilities respectively.[2,26] Excel 2013 (Microsoft) and SPSS Statistics version 26 (IBM) were used for the statistical analyses. A P value $< .05$ was considered significant.

Results

Table 3 shows that the DDR image groups had higher mean CNR values in general, indicating better foreign body visualization than the CR groups. The edge-enhanced DDR images had the highest mean CNR value overall, which was significantly different ($P = .003$) from those of the CR and the sharpened DDR images. Similar findings also were noted in the dorsoplantar projection and dorsoplantar projection with superficial foreign body subcategories. These results suggest that edge enhancement should be the most useful image postprocessing function for improving wooden, soft tissue foreign body visualization. However, it was difficult to visualize deeply embedded foreign bodies on the dorsoplantar images and all foreign bodies on the lateral images because the mean CNR values were close to 0. In addition, the sharpening function had a negative effect on foreign body visualization for the CR and DDR images. For each image receptor and postprocessing type, the mean CNR values from the dorsoplantar images with the superficial foreign body acquired by different exposure factors also were compared. However, no significant mean differences were found.

The interobserver reliability was fair (ICC = 0.56), and the test-retest reliability was good (mean ICC = 0.65). **Table 4** shows that the edge-enhanced DDR images had the highest mean sensitivity overall and for the detection of the 10 mm foreign body. It was difficult to detect the smallest foreign body (2 mm); however, the original CR images had the second-highest overall sensitivity and the highest sensitivities for detecting the 2 mm and 5 mm foreign bodies. Furthermore, the original and noise-reduced DDR images had the lowest or second lowest mean sensitivities. **Figure 3** shows the original CR, sharpened CR, original DDR, edge-enhanced DDR, noise-reduced DDR, and sharpened DDR images with the superficial 10 mm foreign body.

Discussion

To the authors' knowledge, this is the first study about the effects of image postprocessing of digital radiography on wooden, soft tissue foreign body detection. Results show that the edge-enhancement function has a notably positive effect on the detection of the wooden, soft tissue foreign bodies. These results are expected because the edge of a wooden foreign body is easier to detect in soft tissues when it is enhanced. Previous studies[10,27] reported that edge enhancement was useful in improving the detection of subtle findings on chest

Table 3

Foreign Body Visualization in Terms of CNR

	Foreign body location	Image receptor and postprocessing types, mean CNR (SD): Gp 1–original CR	Gp 2–sharpened CR	Gp 3–original DDR	Gp 4–edge-enhanced DDR	Gp 5–noise-reduced DDR	Gp 6–sharpened DDR	*P* Value	Post hoc test
Dorsoplantar and lateral	Superficial and deep	1.47 (3.22)	1.30 (2.83)	1.92 (3.88)	3.39 (6.67)	1.99 (4.01)	1.78 (3.67)	.003	Gp 4 ≠ Gp 1 Gp 4 ≠ Gp 2 Gp 4 ≠ Gp 6
Dorsoplantar	Superficial and deep	3.44 (3.56)	2.98 (3.19)	4.17 (4.37)	7.20 (7.73)	4.32 (4.50)	3.94 (4.14)	< .001	Gp 4 ≠ Gp 1 Gp 4 ≠ Gp 2 Gp 4 ≠ Gp 3 Gp 4 ≠ Gp 5 Gp 4 ≠ Gp 6
	Superficial	6.79 (1.58)	5.94 (1.61)	8.28 (1.94)	14.28 (4.22)	8.54 (2.03)	7.86 (1.72)	< .001	Gp 2 ≠ Gp 3 Gp 2 ≠ Gp 5 Gp 2 ≠ Gp 6 Gp 4 ≠ Gp 1 Gp 4 ≠ Gp 2 Gp 4 ≠ Gp 3 Gp 4 ≠ Gp 5 Gp 4 ≠ Gp 6
	Deep	0.09 (0.12)	0.02 (0.08)	0.06 (0.30)	0.12 (0.25)	0.09 (0.40)	0.02 (0.26)	.549	-
Lateral	Superficial and deep	–0.49 (0.64)	–0.38 (0.45)	–0.33 (1.02)	–0.41 (0.80)	–0.33 (1.13)	–0.39 (0.72)	.896	-
	Superficial	–1.08 (0.29)	–0.79 (0.26)	–1.21 (0.33)	–1.00 (0.46)	–1.26 (0.48)	–0.99 (0.37)	< .001	Gp 1 ≠ Gp 2 Gp 2 ≠ Gp 3 Gp 2 ≠ Gp 5
	Deep	0.10 (0.16)	0.02 (0.10)	0.55 (0.62)	0.19 (0.60)	0.61 (0.74)	0.22 (0.38)	< .001	Gp 1 ≠ Gp 3 Gp 1 ≠ Gp 5 Gp 2 ≠ Gp 3 Gp 2 ≠ Gp 5 Gp 4 ≠ Gp 5 Gp 5 ≠ Gp 6

Abbreviations: CNR, contrast-to-noise ratio; CR, computed radiography; DDR, direct digital radiography; Gp, group; SD, standard deviation.

radiographs. Although the chest region has high subject contrast, the detection of subtle abnormalities remains challenging. Those previous studies[10,27] demonstrated the positive effect of edge enhancement on aiding subtle abnormality detection. Because wooden, soft tissue foreign bodies can be considered a subtle abnormality, the use of edge enhancement should improve its detection; this also was illustrated by the results.[10,27]

There are discrepancies between the findings presented in Tables 3 and 4. Except for edge-enhanced

DDR, the overall mean sensitivities of DDR were lower than those of CR, and the mean sensitivities of the original CR were comparable with those of the edge-enhanced DDR. The discrepancies could be ascribed to variations in the observers' subjective interpretations, considering only fair interobserver and good test-retest agreements were achieved.

Figure 3 provides further insights. The radiographic contrast between soft tissue and foreign bodies on the original and sharpened CR images appears higher than that of all DDR images except the edge-enhanced image. However, the CR images, especially the sharpened image, had more noise than the DDR images, leading to the lower CNR values. The higher noise on the CR images is expected because CR has a much lower detective quantum efficiency (0.25) than the DDR system (0.6-0.7).[2,28]

Unsharp masking is the common approach to sharpening a medical image that involves a blurred (ie, smoothened) image subtracted from its original.[29,30] The resulting image contains high-frequency information (eg, fine details) with low frequency information removed. Because noise is a form of high-frequency information, this process makes the noise more pronounced.[29] The sharpened CR image clearly illustrates the noise complication, but the sharpened DDR image does not show prominent noise because of the higher detective quantum efficiency of the system.[2,28] Noise reduction is a technique opposite to sharpening. By smoothing or blurring an image, the high-frequency information, including fine details and noise, can be reduced.[31] These considerations explain the CNR findings presented in Table 3.

Although the CR images have prominent noise lowering their CNR values, their sensitivities were higher than most of the DDR images. The weak correlation between CNR and observers' interpretations of pathology visibility is not uncommon.[21] This is because foreign body detection does not depend solely on CNR. Other factors, such as foreign body size and observer's ability to average local image densities during image reading, are important. According to the Rose model,[32] the detection of small objects depends greatly on spatial resolution and the detection of large objects on noise. Because the CR system used in this study had a higher spatial resolution, the original and sharpened CR images for the detection of the 2 mm and 5 mm foreign bodies were comparable with, or even higher than, the edge-enhanced DDR images. However, sensitivity of the edge-enhanced DDR images for detecting the 10 mm foreign body (43.33%) was the highest.[32]

Edge-enhanced DDR had an overall mean sensitivity of 35.13% for foreign body detection, which is higher than the mean sensitivities of DDR without image postprocessing (4.17%) and sonography (30%) that were reported in a similar study.[9] The lower sensitivity of DDR in that study could be because windowing was not attempted during the image interpretation. Another study compared the diagnostic performance of various modalities for detecting wooden, soft tissue foreign bodies; the reported sensitivity of screen-film radiography was 13.6%, sonography 63.6%, CT 72.7%, and magnetic resonance imaging 59.1%.[33] Although the diagnostic performance of edge-enhanced DDR is inferior to those of other modalities, it can be used as an additional diagnostic tool for patients living in rural areas where digital radiography is the only available modality,[6] and wooden foreign bodies found in feet is a common medical condition.[33] This allows patients living in rural areas to avoid long-distance travel to access sonography or CT for foreign body detection, minimizing the emotional, financial, and social costs.[6]

Like sonography, edge-enhanced DDR likely is useful for detecting only superficial foreign bodies.[5,9] When the foreign body overlaps with bone or is in thicker tissue, it is obscured. Orthogonal projection is essential to maximize foreign body detection rate. However, specific exposure factor optimization is not necessary because the results of this study show that the exposure factor did not have a significant effect on foreign body visualization.[2]

This study has some limitations such as analyzing a single type of wood (toothpick) with 3 lengths inserted into 2 locations of the porcine feet to simulate clinical situations. Also, radiologic technologists with a maximum 3 years of plain radiography experience were included as observers, which might negatively affect the test-retest and interobserver reliabilities. However, in a previous digital radiography postprocessing study, more experienced radiologists who received specific training as observers could not reach an acceptable agreement (Cronbach $\alpha = 0.4$).[10] This situation can

Table 4

Performance Figures of Image Receptor and Postprocessing Types for Detection of Foreign Bodies of Different Sizes

Foreign body length, mm	Performance measure	Image receptor and postprocessing types, mean (SD), %					
		Gp 1 – original CR	Gp 2 – sharpened CR	Gp 3 – original DDR	Gp 4 – edge-enhanced DDR	Gp 5 – noise-reduced DDR	Gp 6 – sharpened DDR
2, 5, and 10	Sensitivity	33.32 (27.74)	29.32 (29.72)	19.65 (23.76)	35.13 (28.52)	19.12 (18.78)	27.78 (30.43)
	Specificity	87.50 (13.69)	66.67 (30.28)	87.50 (13.69)	91.67 (20.41)	95.83 (10.21)	100.00 (0.00)
	Accuracy	39.90 (24.20)	33.84 (25.74)	28.13 (19.47)	42.19 (23.78)	29.03 (16.57)	35.59 (27.16)
2	Sensitivity	30.00 (28.28)	24.08 (34.02)	13.33 (17.51)	29.63 (25.99)	18.50 (18.13)	26.92 (30.65)
	Specificity	87.50 (13.69)	66.67 (30.28)	87.50 (13.69)	91.67 (20.41)	95.83 (10.21)	100.00 (0.00)
	Accuracy	46.43 (19.56)	37.18 (23.03)	34.52 (9.49)	48.72 (15.89)	42.31 (12.64)	44.12 (23.46)
5	Sensitivity	38.90 (27.02)	35.00 (24.29)	25.93 (37.64)	31.48 (35.44)	20.37 (30.97)	30.30 (37.54)
	Specificity	87.50 (13.69)	66.67 (30.28)	87.50 (13.69)	91.67 (20.41)	95.83 (10.21)	100.00 (0.00)
	Accuracy	53.85 (18.20)	44.05 (17.15)	44.87 (23.03)	50.00 (23.20)	43.59 (22.65)	48.89 (27.54)
10	Sensitivity	31.67 (32.51)	28.33 (33.12)	20.37 (20.40)	43.33 (30.11)	18.52 (19.48)	25.92 (27.82)
	Specificity	87.50 (13.69)	66.67 (30.28)	87.50 (13.69)	91.67 (20.41)	95.83 (10.21)	100.00 (0.00)
	Accuracy	47.62 (23.76)	39.29 (25.05)	41.03 (11.58)	57.14 (18.63)	42.31 (13.54)	48.72 (19.26)

happen when an image interpretation task is challenging.[34] In addition, individual observers might require different durations to adapt to the postprocessed image's quality.[27] Limited simulation settings were covered in this experimental study. Nevertheless, experimental studies are common for the investigation of foreign body detection. More images were included in this study compared with similar studies.[2,9,13,35] Also, the various lengths of wooden foreign bodies, the digital radiography systems, and the postprocessing functions covered in the present study were comparable with or even exceeded those in similar studies.[9-12,27,36,37]

Conclusion

This study showed that the edge-enhancement image postprocessing function of the DDR system can improve wooden, soft tissue foreign body detection. This can be considered an additional tool in rural areas

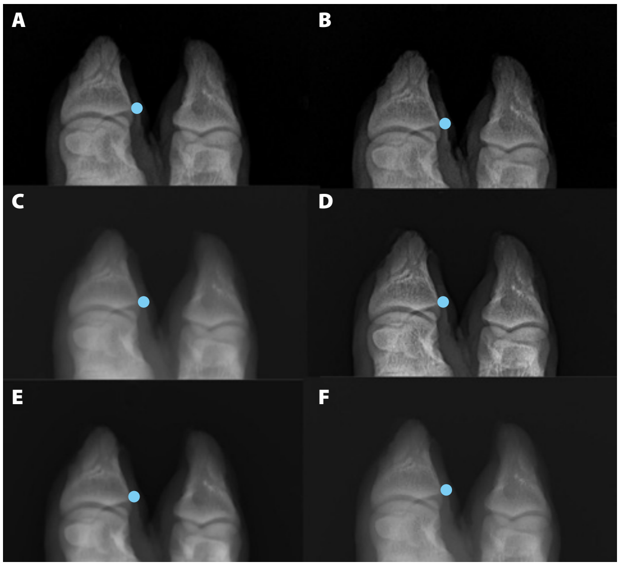

Figure 3. *Cropped dorsoplantar images with the superficial 10 mm foreign body marked by a blue circle. A. Original computed radiography (CR) image with obvious density differences between structures, including foreign bodies (contrast), and noise. Trabecular pattern is visualized (spatial resolution). B. Sharpened CR image with more obvious density differences between structures and noise. Trabecular pattern is visualized better compared with image A. C. Original direct digital radiography (DDR) image with the lowest density differences between structures. Trabecular pattern is blurry without obvious noise. D. Edge-enhanced DDR image with density differences comparable to image B but with less noise and sharp trabecular pattern. E. Noise-reduced DDR image with no obvious noise and density differences higher than image C, but the trabecular pattern is blurry. F. Sharpened DDR image with no obvious noise and density differences higher than image C. Trabecular pattern is less blurry compared with image E. Images courtesy of the authors.*

for detecting suspected superficial wooden, foreign bodies in soft tissues. Because of this study's limitations, caution is required for transferring the results (eg, sensitivity, specificity, accuracy) to clinical practice. Further studies could include images demonstrating a wider range of wooden, soft tissue foreign body types, sizes, and locations acquired by different digital radiography systems in multiple centers. Images should be postprocessed by image-enhancement functions and collected for a large-scale, subjective image analysis involving multiple experienced radiologists. This would allow the diagnostic value of the image processing functions to be comprehensively evaluated.

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The authors would like to thank the radiologic technologists, who participated in this study as observers, for their contributions of time and effort. This study did not receive any specific grants from funding agencies in the public, commercial, or not-for-profit sectors.

Received May 3, 2021; accepted after revision August 25, 2021.

Reprint requests may be mailed to the American Society of Radiologic Technologists, Publications Department, 15000 Central Ave SE, Albuquerque, NM 87123-3909, or emailed to publications@asrt.org.

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