THE SOUTH AFRICAN RADIOGRAPHER volume 56 number 2 | NOVEMBER 2018
OPEN ACCESS online only

peer reviewed **ORIGINAL ARTICLE**

Comparison of the performance of computed radiography and direct radiography in glass soft tissue foreign body visualisation

Samantha A. Petri *BSc Hons* | **Curtise K.C. Ng** *PhD, BSc Hons*

Discipline of Medical Radiation Sciences, School of Molecular and Life Sciences, Curtin University, GPO Box U1987, Perth, Western Australia 6845, Australia

Abstract

Purpose: The purpose of the study was to investigate the performance of recent computed radiography (CR) and direct radiography (DR) in glass soft tissue foreign body (FB) visualisation in terms of their overall performance, and effects of sizes and locations of FB, and exposure parameters on the visualisation.

Methods: Eighty anteroposterior (AP) and 80 lateral images of chicken legs with five sizes of FBs inserted into two locations were taken by our CR and DR systems using four exposure parameter combinations. Contrast-to-noise ratio (CNR), and visual grading analysis (VGA), were employed to assess the FB visibility. The CNR and VGA data were analysed using descriptive and inferential statistics.

Results: The mean CNR value, 3.89 and median VGA score, 1 (definitely invisible) of all CR images were statistically significantly lower than the mean CNR value, 9.47 ($p<0.001$) and median VGA score, 2 (possible visible [but uncertain]) of all DR images ($p<0.05$) respectively. Despite this, the FBs were visible on CR (median VGA score: 3 - visible but could be shown better) and DR (median VGA score: 4 - definitely visible) lateral images (without FBs overlapping with bone). The smallest FBs visible on CR and DR lateral images were 2 and 1 mm respectively. The factors of FB depths and kV settings did not have any statistically significant effects on FB visibility ($p>0.05$).

Conclusion: The performance of recent DR system in glass soft tissue FB visualisation appears more superior to CR. DR should be used to take orthogonal (AP and lateral) images for detecting any small FBs.

Keywords digital radiography, glass visibility, indirect flat panel detector, photostimulable phosphor plate receptor

INTRODUCTION

Soft tissue foreign bodies (FBs) can cause continued pain, tissue infection, and nerve and blood vessel injury if they are undetected on initial clinical examinations and retained in the tissues.[1-5] Missed FBs can lead to malpractice lawsuits against physicians.[3,4] A study shows that this accounted for about one third of wound malpractice claims from 1975 to 1993 in Massachusetts, United States.[6] Many studies have investigated the use of different medical imaging modalities such as general radiography, ultrasound, computed tomography, and magnetic resonance imaging to detect soft tissue FBs.[5,7-9] Imaging guidelines such as Government of Western Australia's diagnostic imaging pathway for suspected FBs have been established to guide physicians through the appropriate FB diagnostic process.[10]

Among different soft tissue FBs such as metal, glass, wood, plastic, acrylics, stone and graphite,[5,7] wood is the most common type of FB found in wounds; glass is the second common one.[1] Wood is a radiolucent material.[5] Ultrasound should be used as the frontline imaging modality for detecting suspected wood FBs.[5,10] As glass is radiopaque,[5,11] general radiography is considered the initial imaging modality of choice for glass FBs.[5,10] However, technical parameters such as dynamic range and exposure latitude of image receptors could affect its visibility. Glass FBs might not be detected in general radiography examinations because of reasons such as use of screen-film radiography, and FBs being too small and overlapping with anatomical structures.[5]

Although a number of studies have explored the use of screen-film radiography for detecting glass soft tissue FBs including the effects of their sizes and locations on the visualisation,[12-14] only one study directly comparing the detection performance of the two digital radiography technologies, computed radiography (CR) and direct radiography (DR), could be located in the literature. In this previous study, anteroposterior (AP) and lateral images of chicken legs with 1, 2 or 3 mm sized glass piece inserted were taken using CR and DR (indirect flat panel detector [FPD]) with 12 combinations of tube voltage and milliampere second (mAs) settings, and viewed by radiologic technologists (radiographers) to assess the performance of CR and DR in visualisation. The findings of this study show that CR performed better than DR in glass soft tissue FB detection. The FB sizes and exposure factors did not affect CR performance but had effect on DR.[4]

Apparently, the results of this previous study[4] are not in line with the current knowledge of CR and DR technologies because the indirect FPD system is able to provide the best image quality and low-contrast performance among all digital radiography technologies.[15-17] Low-contrast performance is essential for soft tissue FB visualisation.[18,19] One possible explanation for this discrepancy could be the use of older models of CR and DR systems in the study which were introduced in the market in 2003 and 2001 respectively. Apart from this issue, their FBs were not systematically inserted into soft tissue. The effects of FBs overlapping with bone and depths of FB in the soft tissue on visualisation could not be assessed properly.[4]

The purpose of our study was to investigate the performance of more recent CR

and DR (indirect FPD) (launched in the last 10 years) in glass soft tissue FB visualisation in terms of their overall performance, and effects of sizes and locations of FB (including FBs superimposed on bone and depths of FB in soft tissue), and exposure parameters on the visualisation on CR and DR images.

MATERIALS AND METHODS

• *Experimental model*

Our study was an experimental study. The institutional review board approval was obtained on 6 February 2017. Chicken legs were used to simulate human thumbs, as employed in previous studies.[4,12] A needle was used to create a puncture wound (tunnel) within soft tissue of each chicken leg along the sagittal plane in the centre of the tibia with a depth of either 1 mm (superficial) or 1 cm from the skin surface (deep). A 0.5, 1, 2 or 3 mm blade shaped piece of clear unleaded glass was introduced by tweezers into each puncture wound. Both the needle and tweezers had markers to indicate the two depths (superficial and deep) for placing each glass piece in an appropriate location.[4,7,12,20] Any air in the wound was ignored as this may be present in clinical situations.[5,14]

• *Image acquisition equipment*

A Shimadzu RADspeed general radiography unit with total filtration of 3.96 mm Al, Agfa CR 30-X (CR) and Canon CXDI-70C wireless caesium iodide (CsI) FPD (DR) systems were used in our study. The CR system was introduced in the market in 2009; the DR system was launched in 2011. The size of the selected CR cassette was 35 x 43 cm (with the pixel size and matrix, 100 µm and 3480 x 4248) which was the same size as the DR detector (with the pixel size and matrix, 125 µm and 2800 x 3408) for a comparison purpose.[21,22] Quality assurance of these systems were carried out by our equipment suppliers regularly.

• *Image acquisition parameters*

AP and lateral projections were performed for each chicken leg and a radiopaque marker was put next to the puncture site to indicate the entry point of FB as per the standard clinical practice.[4] Due to the approach used for the placement of the FBs, each AP image had a glass piece superimposed on the centre of the tibia; all lateral images did not have this.

A pilot study was carried out to determine the appropriate combinations of tube voltage and mAs settings for the formal trial. Lateral projections were taken for the chicken leg which had a 3 mm glass piece inserted to the deep location with a source-to-image distance (SID) of 100 cm, a central ray directed to the centre of the leg, a beam collimation including skin margins, a focal spot size of 0.6 mm and no anti-scatter grid, and variable settings of tube voltage (between 40 and 60 kV at 5 kV increments) and mAs (1.6 or 3.2) by the CR and DR systems. The image processing algorithms for hand radiography were used to process all image data.[4] The 20 lateral images acquired (2 digital radiography systems x 5 tube voltage settings x 2 mAs values) in digital imaging and communications in medicine (DICOM) format were exported to a computer workstation with an open-source image processing programme (ImageJ 1.51a, National Institutes of Health, United States) to measure the mean pixel values (MPVs) of four regions of interest (ROIs) including the glass FB and three surrounding (background) areas, and standard deviations of pixel values (PVSDs) of the background areas for contrast-to-noise ratio (CNR) calculation.[23] Each ROI contained about 20 pixels. Figure 1 shows the locations of the 4 ROIs on a lateral image. The CNR was used as the parameter for the objective image quality assessment in our study because the contrast resolution is crucial for soft tissue FB visualisation.[18,19] Also, it could directly evaluate the visibility of glass FBs on images in an objective manner.[24] The CNR was calculated using the following equation.[23]

$$(MPV_{FB} - \text{Average } MPV_{Background}) / \text{Average } PVSD_{Background} \quad (1)$$

In the formal trial, 160 chicken leg images were acquired (2 digital radiography systems [CR and DR] x 5 glass FB sizes [0, 0.5, 1, 2 and 3 mm] x 2 projections [AP and lateral] x 2 depths [superficial and deep] x 4 combinations of tube voltage and mAs settings [40, 45, 50 and 55 kV and a fixed 3.2 mAs] with the same settings of SID, central ray, beam collimation, focal spot size, image processing algorithm and no anti-scatter grid as employed in the pilot study. For the setting of the 0 mm glass FB size, it referred to the situation that no glass was put into the chicken legs for producing 32 control images. The 4 combinations of tube voltage and mAs settings were those used in the pilot study that produced the images with the top 4 CNR values (first to forth highest image quality). Figures 2a-d show some examples of CR and DR images taken in the formal trial.

» Image analysis

Objective and subjective image analysis approaches were used in our study to assess the performance of CR and DR in glass soft tissue FB visualisation. For the objective analysis, a CNR value based on the pixel values of the FB and background areas of each image (except those in the control group) was calculated as per the method described for the pilot study. A higher CNR value represented better FB visualisation performance.[24] Visual grading analysis (VGA) was used as the subjective image analysis approach. Six final

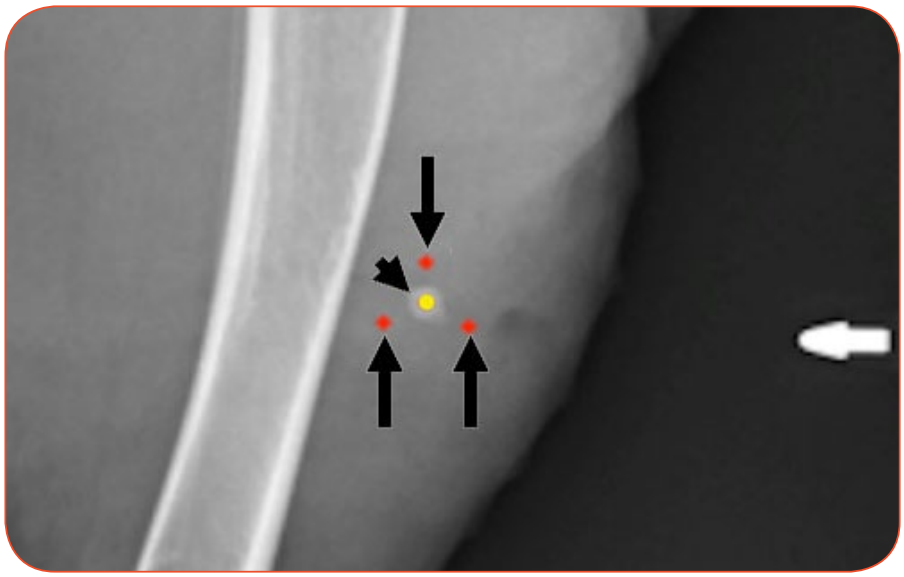

Figure 1. Locations of the four regions of interest, glass foreign body (short black arrow) and three 3 background areas (long black arrows) on a lateral chicken leg image for contrast-to-noise ratio calculation.

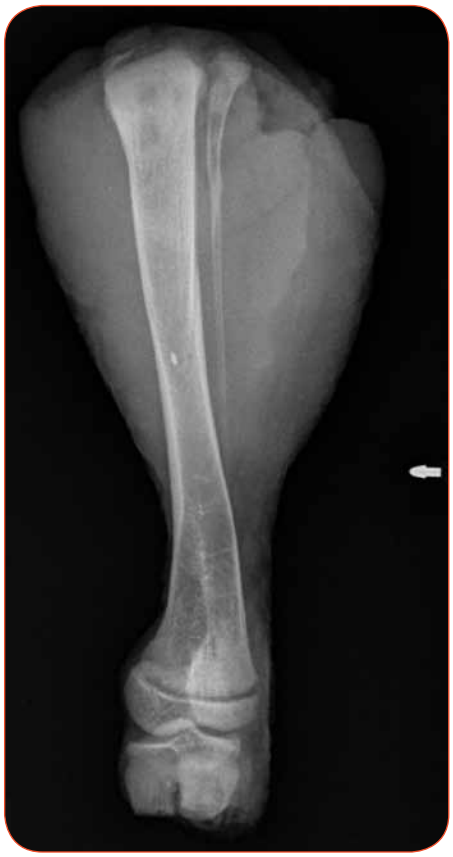

Figure 2a. Computed radiography (CR) anteroposterior (AP) image of a chicken leg with a 3 mm sized glass piece inserted to the deep location and acquired using 50 kV and 3.2 milliampere seconds.

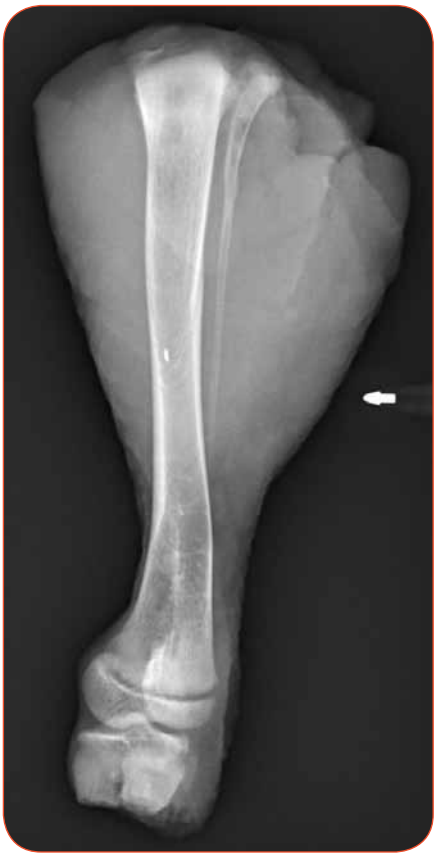

Figure 2b. Direct radiography (DR) AP image of a chicken leg with a 3 mm sized glass piece inserted to the deep location and acquired using 50 kV and 3.2 milliampere seconds.

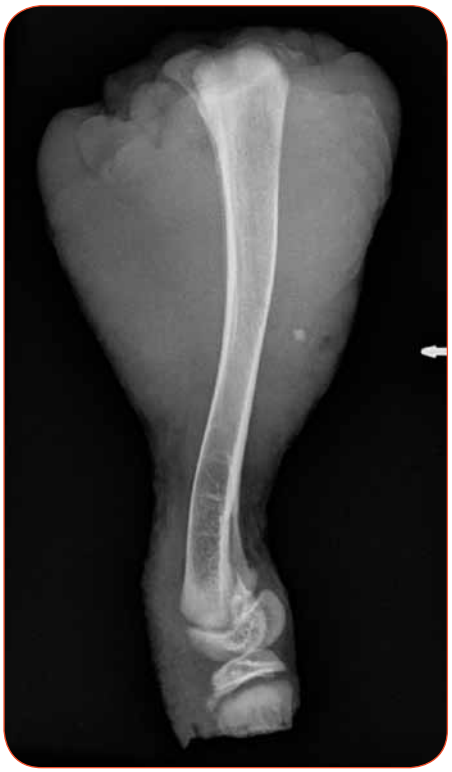

Figure 2c. CR lateral image of a chicken leg with a 3 mm sized glass piece inserted to the deep location and acquired using 50 kV and 3.2 milliampere seconds.

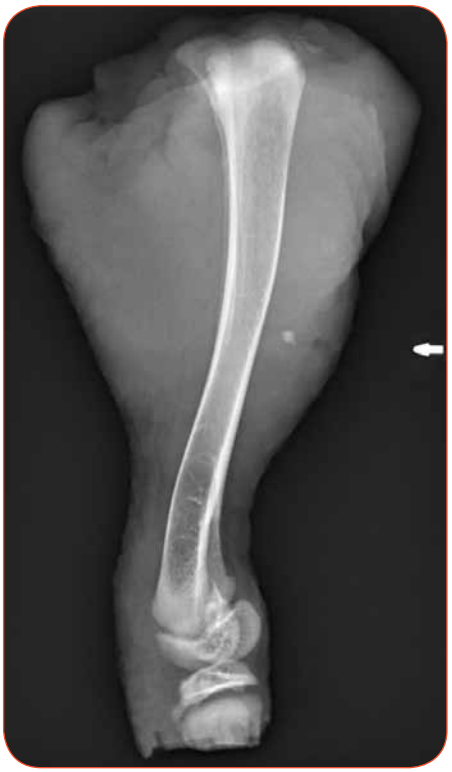

Figure 2d. DR lateral image of a chicken leg with a 3 mm sized glass piece inserted to the deep location and acquired using 50 kV and 3.2 milliampere seconds.

year medical imaging students who had completed training in image interpretation within their undergraduate programme and additional training for the VGA, and did not have any visual impairment were employed in our study as observers.[25] They were required to rate the visibility of the FB on each image using a scale of 1-4 (*1=definitely invisible, 2=possibly visible [but uncertain], 3=visible [but could be shown better] and 4=definitely visible*) and not informed about the digital radiography systems and exposure factors used for taking the images, and whether they contained any FBs.

One hundred and sixty images taken in the formal trial and an additional of 12 (6 CR and 6 DR) images randomly selected from these 160 images were presented to each observer for grading after informed consent was obtained. The display order of the 172 images was randomised. A computer workstation with OsiriX Lite version 8.5.1 (Pixmeo, Switzerland) and a 55 cm (with 1920 x 1080 pixels) BenQ GW2270-T light emitting diode monitor was used to display the images. The observers were not allowed to adjust the display window setting but could magnify the images if necessary.[4] They individually completed the VGA using the same workstation at the same location under the conditions recommended by the American College of Radiology – American Association of Physicists in Medicine – Society for Imaging Informatics in Medicine Technical Standard for Electronic Practice of Medical Imaging including the ambient lighting level set to 31.7 lx, optimal air flow, temperature and humidity, and minimal noise from computer equipment in the viewing environment.[26]

» Statistical analysis

The CNR values and VGA scores were analysed using descriptive and inferential statistics. For the CNR and VGA data not from the control group, they were divided into cohorts based on the digital radiography systems used, sizes and locations of FB, and exposure parameters employed. For each group, mean and standard deviation (SD) of CNR values, and median and interquartile range (IQR) of VGA scores were calculated. The Kolmogorov-Smirnov (KS) test was used to assess the normality of CNR values. Mean CNR values between cohorts were compared through parametric tests (either a t-test [for 2 groups] or one-way analysis of variance [ANOVA] [for 3 cohorts or more]) when the values were normally distributed. Otherwise, non-parametric tests, Mann-Whitney (MW) (for 2 groups) and Kruskal-Wallis (KW) (for 3 cohorts or more) tests were used to compare the median CNR values. The MW and KW tests were also used to compare the median VGA scores between groups. Only median and IQR were calculated for the VGA scores of the control images. The intra-class correlation coefficient (ICC) was employed to assess the inter-rater and intra-rater reliabilities of the VGA data.[4] The ICC values less than 0.40, between 0.40 and 0.59, between 0.60 and 0.74, and between 0.75 and 1.00 represented poor, fair, good and excellent agreements respectively.[27] The SPSS Statistics version 22 (IBM, United States) was used in statistical analysis. A p-value less than 0.05 obtained from inferential statistics was considered statistically significant.[4]

RESULTS

The ICC values for the inter- and intra-rater reliabilities of the VGA were 0.61 ($p<0.001$) and 0.68-1.00 ($p<0.005$) respectively. These represent the inter-rater reliability was good; the intra-rater reliability was between good and excellent. The median VGA score of all control images was 1 (IQR: 0.00) demonstrating FBs definitely invisible. The following results are only for the images not from the control group.

The KS test result indicates the CNR values were normally distributed. The parametric tests were used to compare the mean CNR values. The mean CNR value (3.89 [SD: 3.66]) and median VGA score (1 [IQR: 0.75]) of all CR images were statistically significantly lower than the mean CNR value (9.47 [SD: 7.69]) and median VGA score (2 [IQR: 0.75]) of all DR images ($p<0.001$ and $p<0.05$) respectively. This demonstrates the overall performance of DR in glass soft tissue FB visualisation was better than that of CR. The CR median VGA score of 1 represents the system was definitely unable to visualise the FBs while the FBs on the DR images were just possibly visible (median VGA score: 2).

Table 1 shows further comparisons of mean CNR values and median VGA scores after sub-dividing the CR and DR image data based on the projections. The CNR values and VGA scores of CR and DR lateral images were statistically significantly higher than those of AP ones. The VGA scores demonstrate both CR and DR systems were definitely unable to visualise any FBs when they were superimposed on bone (on AP images). However, DR was definitely able to visualise FBs on lateral images (when they did not overlap with bone) while CR was able to do this but the visibility could be improved.

Tables 2 and 3 demonstrate the effects of sizes and depths of FB, and exposure parameters (kV) on the visualisation on AP and lateral images respectively. Table 2 shows nearly all median VGA scores of the AP images were 1 (FBs definitely invisible) which are in line with the findings illustrated in Table 1. Despite this, the mean CNR values of the biggest FB were statistically significantly greater than the smaller ones for both CR and DR AP images

Table 1. Effect of foreign bodies overlapping with bone on its visualisation on computed radiography and direct radiography images

IMAGE	FOREIGN BODY VISIBILITY INDICATOR	PROJECTION*		P-VALUE
		ANTEROPOSTERIOR	LATERAL	
Computed Radiography	**Mean CNR Value (SD)**	2.03 (2.97)	5.76 (3.36)	<0.001
	Median VGA Score (IQR)†	1.00 (0.00)	3.00 (0.75)	<0.001
Direct Radiography	**Mean CNR Value (SD)**	5.29 (5.98)	13.65 (6.96)	<0.001
	Median VGA Score (IQR)†	1.00 (0.38)	4.00 (0.75)	<0.001

CNR=contrast-to-noise ratio; IQR=interquartile range; SD=standard deviation; VGA=visual grading analysis
** Every anteroposterior image had a foreign body superimposed on bone while all lateral images did not have this*
† Scale of 1-4 (1=definitely invisible; 2=possibly visible [but uncertain]; 3=visible [but could be shown better]; 4=definitely visible)

Table 2. Anteroposterior images: effects of sizes and depths of foreign body (FB) and exposure parameters (kV) on the visualisation using computed radiography and direct radiography

FB VISIBILITY INDICATOR	COMPUTED RADIOGRAPHY IMAGE				P-VALUE/ POST-HOC TEST	DIRECT RADIOGRAPHY IMAGE				P-VALUE/ POST-HOC TEST
Mean CNR Value (SD)	**FB SIZE (mm)**									
	0.5	**1**	**2**	**3**	<0.001 / 0.5≠3,1≠3, 2≠3	**0.5**	**1**	**2**	**3**	<0.001 / 0.5≠3,1≠3, 2≠3
	1.51 (1.67)	1.05 (2.99)	0.32 (1.29)	3.30 (1.10)		2.21 (3.99)	5.02 (2.70)	1.25 (2.16)	13.82 (6.74)	
	FB DEPTH*									
	Superficial		**Deep**		>0.05	**Superficial**		**Deep**		>0.05
	1.36 (2.23)		3.13 (3.86)			5.99 (5.65)		5.66 (7.74)		
	EXPOSURE PARAMETER (kV)									
	40	**45**	**50**	**55**	>0.05	**40**	**45**	**50**	**55**	>0.05
	1.41 (1.91)	1.35 (2.95)	2.15 (3.04)	3.97 (4.30)		5.70 (5.08)	4.56 (4.82)	5.42 (6.92)	7.43 (9.33)	
Median VGA Score (IQR)†	**FB SIZE (mm)**									
	0.5	**1**	**2**	**3**	>0.05	**0.5**	**1**	**2**	**3**	<0.05 / 0.5≠1,0.5≠2
	1.00 (0.00)	1.00 (0.75)	1.00 (0.38)	1.00 (0.00)		1.50 (0.88)	1.00 (0.00)	1.00 (0.00)	1.00 (0.38)	
	FB DEPTH*									
	Superficial		**Deep**		>0.05	**Superficial**		**Deep**		>0.05
	1.00 (0.00)		1.00 (0.38)			1.00 (0.00)		1.00 (0.75)		
	EXPOSURE PARAMETER (kV)									
	40	**45**	**50**	**55**	>0.05	**40**	**45**	**50**	**55**	>0.05
	1.00 (0.00)	1.00 (0.00)	1.00 (0.38)	1.00 (0.38)		1.00 (0.75)	1.00 (0.00)	1.00 (0.75)	1.00 (0.00)	

CNR=contrast-to-noise ratio; IQR=interquartile range; SD=standard deviation; VGA=visual grading analysis
** Superficial=1 mm from the skin surface; deep=1 cm from the skin surface*
† Scale of 1-4 (1=definitely invisible; 2=possibly visible [but uncertain]; 3=visible [but could be shown better]; 4=definitely visible)

(p<0.001). Similarly, both mean CNR values and median VGA scores of the biggest FB on CR and DR lateral images were statistically significantly greater than the values of the smaller FBs (p<0.001). These indicate the FB sizes affected its visualisation. Both CR and DR systems were possibly able to visualise a 0.5 mm sized glass FB when it was not superimposed on bone (Table 3). However, no other statistically significant finding is noted in Tables 2 and 3 representing that the depths of FB and exposure parameters did not affect the FB visualisation.

DISCUSSION

The findings of our study show the overall performance of recent DR (indirect FPD) technology in glass soft tissue FB visualisation appears better than that of current CR systems. These findings are within our expectation because the indirect FPD system has the best image quality and low-contrast performance when compared with other digital radiography technologies.[15-17] This superior performance is crucial for soft tissue FB visualisation[18,19] and contributed by the higher detective quantum efficiency (DQE) of the indirect FPD system, 0.6-0.7. In contrast, the CR DQE is only about 0.25 (single-sided read)-0.35 (dual-sided read).[16] Although this concept was discussed in the only article about the comparison of the CR and DR performance in the glass soft tissue FB detection published by Sheridan and McNulty in 2016, their findings indicated CR performed better than DR, and they believed these were due to their tube voltage settings (40, 45, 50 and 55 kV) used for image acquisition.[4] The same tube voltage settings were used in our study. However, our CNR values and VGA scores did not show the use of different kV settings caused any statistically significant difference (Tables 2 and 3). Similar findings in relation to the effect of tube voltage settings were noted in the study by Sheridan and McNulty for their CR system but not for their DR.[4]

Apparently, these discrepancies might not be just simply related to DQE of the digital radiography technologies. Their image processing capabilities might also play a role in these. As per a study about the optimum tube voltage for pelvic DR published in 2015, acceptable image quality could be obtained even with extreme kV settings used because the recent CR and DR systems normally had advanced image processing capabilities such as multi-frequency processing. The effect of tube voltage selection on image quality was less prominent when using current systems.[28] Although the image processing factor was mentioned in the article by Sheridan and McNulty, it was not further discussed in relation to their findings as they determined this matter was beyond the scope of their study.[4] Since both CR and DR systems used in our study had the advanced image processing capabilities including multi-frequency processing,[28,29] it seems the main contributing factor of the superior performance of our DR system should be its excellent DQE.[15-19]

Table 3. Lateral images: effects of sizes and depths of foreign body (FB) and exposure parameters (kV) on the visualisation using computed radiography and direct radiography

FB VISIBILITY INDICATOR	COMPUTED RADIOGRAPHY IMAGE				P-VALUE/ POST-HOC TEST	DIRECT RADIOGRAPHY IMAGE				P-VALUE/ POST-HOC TEST
Mean CNR Value (SD)	**FB SIZE (mm)**									
	0.5	**1**	**2**	**3**	<0.001 / 0.5≠3,1≠3, 2≠3	**0.5**	**1**	**2**	**3**	<0.001 / 0.5≠3, 1≠3, 2≠3
	2.48 (0.99)	5.09 (3.66)	5.92 (1.75)	9.54 (1.86)		6.34 (1.53)	12.80 (2.66)	13.81 (3.91)	21.65 (7.41)	
	FB DEPTH*									
	Superficial		**Deep**		>0.05	**Superficial**		**Deep**		>0.05
	5.47 (3.81)		6.04 (2.94)			12.11 (5.11)		15.19 (8.30)		
	EXPOSURE PARAMETER (kV)									
	40	**45**	**50**	**55**	>0.05	**40**	**45**	**50**	**55**	>0.05
	4.70 (2.51)	5.15 (3.62)	6.36 (3.37)	6.81 (3.98)		9.80 (4.14)	14.79 (6.53)	13.24 (5.69)	16.77 (3.40)	
Median VGA Score (IQR)†	**FB SIZE (mm)**									
	0.5	**1**	**2**	**3**	<0.001 / 0.5≠3, 1≠3	**0.5**	**1**	**2**	**3**	<0.001 / 0.5≠2, 0.5≠3
	2.00 (0.88)	1.50 (0.75)	3.00 (0.75)	3.5 (0.75)		2.00 (1.63)	3.00 (1.00)	4.00 (0.75)	4.00 (0.00)	
	FB DEPTH*									
	Superficial		**Deep**		>0.05	**Superficial**		**Deep**		>0.05
	2.00 (0.75)		3.00 (0.75)			4.00 (0.75)		4.00 (0.75)		
	EXPOSURE PARAMETER (kV)									
	40	**45**	**50**	**55**	>0.05	**40**	**45**	**50**	**55**	>0.05
	2.50 (0.75)	2.50 (0.75)	2.50 (0.75)	3.00 (0.38)		4.00 (0.75)	3.50 (0.38)	4.00 (0.38)	4.00 (0.75)	

CNR=contrast-to-noise ratio; IQR=interquartile range; SD=standard deviation; VGA=visual grading analysis
** Superficial=1 mm from the skin surface; deep=1 cm from the skin surface*
† Scale of 1-4 (1=definitely invisible; 2=possibly visible [but uncertain]; 3=visible [but could be shown better]; 4=definitely visible)

Our study findings (VGA scores) also demonstrate that it was difficult for the observers to detect the FBs with bone superimposed on them (Tables 1 and 2). When they did not overlap with bone, our DR system was definitely able to visualise them, and they were also visible on the CR images although the performance could be improved. The effect of this factor was statistically significant (Table 1). Similar findings were noted in the literature as well.[4,5,12] This reinforces the importance of using orthogonal projection for FB radiography.[4,12]

In a previous study about glass soft tissue FB visualisation using screen-film radiography, it was reported that the average detection rates of 0.5, 1 and 2 mm sized glass FBs were 61%, 83% and 99% respectively.[12] Our VGA scores also reveal similar findings (Table 3). For example, 0.5 mm sized glass FB could possibly be visible on CR and DR lateral images although not certain. The smallest FBs that could be visible on CR and DR images were 2 and 1 mm respectively. In the study by Sheridan and McNulty,[4] the smallest FBs which could be visualised by their CR and DR systems were 1 and 3 mm respectively. These highlight 0.5-2 mm was the limited detection size range for digital radiography technologies in line with the performance of screen-film radiography.[12] The exact limit would depend on the particular digital radiography technology used.[4]

Although Sheridan and McNulty[4] suggested that the FB depths might have an effect on glass soft tissue visualisation, this was not investigated in their study. Our study findings show that the FB depths did not have any statistically significant effect on FB visibility (Table 3). However, it is noted that the visibility of superficial FB on CR lateral images (median VGA score: 2) appeared not as good as the deep FB (median VGA score: 3). One possible explanation for this could be the different thicknesses of the peripheral and central regions of the chicken legs leading to different subject contrasts. As per our study settings, the superficial FB was located in the peripheral region while the deep FB was within the central area. Since these two regions had different subject contrasts, this might affect the visualisation of superficial and deep FBs on CR images.[30] However, the superior low-contrast performance of our DR system might be able to compensate this and was able to definitely visualise the superficial and deep FBs.[15-17]

Our study has several limitations. Firstly, the final year medical imaging students were employed as the observers for the VGA. Nonetheless, this allowed more observers participated in the image analysis when compared with the other studies.[4,12] Also, our VGA findings agreed with our CNR values, and good inter-rater and intra-rater reliabilities were achieved. This was considered an acceptable practice for the image analysis.[25] Secondly, only a consumer-grade monitor was used for the VGA. However, a recent study reported

that there was no statistically significant difference in perceived image quality between medical- and consumer-grade monitors, and with and without DICOM grayscale standard display function calibrations.[31] Thirdly, our study was an experimental study involving a limited number of simulated settings. For future studies, the evaluation of the performance of digital radiography technologies in glass soft tissue FB visualisation should be based on a notable amount of real clinical cases with involvement of multiple radiologists and digital radiography systems. [2-4,12,18,19]

CONCLUSION

Our study reveals that the performance of recent DR systems in glass soft tissue FB visualisation seems better than that of current CR systems. However, it appears difficult for the observers to detect the FBs on both CR and DR images with bone superimposed on them. When there is no superimposition issue, the smallest FBs that can be visible on DR and CR images are 1 and 2 mm respectively. The factors of FB depths and tube voltage settings do not have any statistically significant effects on FB visibility. A recent DR system (if available) should always be used to take orthogonal (AP and lateral) images as the frontline imaging examination for detecting any small glass soft tissue FBs.

ACKNOWLEDGMENTS

The authors would like to thank the medical imaging students who participated in our study as the observers for their contributions of time and effort.

CONTRIBUTIONS OF AUTHORS

SAP (Curtin University) was the main researcher and responsible for study design, data collection, analysis and interpretation, and drafting the manuscript. CKCN (Curtin University) assisted with study design, data collection, analysis and interpretation, and was responsible for providing critical comments and recommendations and final approval of the submitted manuscript.

DECLARATION OF CONFLICT/COMPETING INTEREST

The authors declared no conflicts of interest.

REFERENCES

1. Levine MR, Gorman SM, Young CF, Courtney DM. Clinical characteristics and management of wound foreign bodies in the ED. Am J Emerg Med, 2008; 26 [8]: 918-922.
2. Tuncer S, Ozcelik IB, Mersa B, Kabakas F, Ozkan T. Evaluation of patients undergoing removal of glass fragments from injured hands: a retrospective study. Ann Plast Surg, 2011; 67 [2]: 114-118.
3. Ozsarac M, Demircan A, Sener S. Glass foreign body in soft tissue: possibility of high morbidity due to delayed migration. J Emerg Med, 2011; 41 [6]: e125-e128.
4. Sheridan N, McNulty JP. Computed radiography versus indirect digital radiography for the detection of glass soft-tissue foreign bodies. Radiography, 2016; 22 [3]: 223-227.
5. Jarraya M, Hayashi D, de Villiers RV, Roemer FW, Murakami AM, Cossi A, Guermazi A. Multimodality imaging of foreign bodies of the musculoskeletal system. Am J Roentgenol, 2014; 203: W92-W102.
6. Karcz A, Korn R, Burke MC, Caggiano R, Doyle MJ, Erdos MJ, Green ED, Williams K. Malpractice claims against emergency physicians in Massachusetts: 1975-1993. Am J Emerg Med, 1996; 14 [4]: 341-345.
7. Javadrashid R, Fouladi DF, Golamian M, Hajalioghli P, Daghighi MH, Shahmorady Z, Niknejad MT. Visibility of different foreign bodies in the maxillofacial region using plain radiography, CT, MRI and ultrasonography: an in vitro study. Dentomaxillofac Radiol, 2015; 44 [4]: 20140229.
8. Lari SS, Shokri A, Hosseinipanah SM, Rostami S, Sabounchi SS. Comparative sensitivity assessment of cone beam computed tomography and digital radiography for detecting foreign bodies. J Contemp Dent Pract, 2016; 17 [3]: 224-229.
9. Kaviani F, Javad Rashid R, Shahmoradi Z, Gholamian M. Detection of foreign bodies by spiral computed tomography and cone beam computed tomography in maxillofacial regions. J Dent Res Dent Clin Dent Prospects, 2014; 8 [3]: 166-171.
10. Government of Western Australia. Diagnostic imaging pathways - foreign body (suspected). Perth, WA: Government of Western Australia; 2013. [Cited 2018 February 15]. Available from: http://www.imagingpathways.health.wa.gov.au/index.php/imaging-pathways/musculoskeletal-trauma/miscellaneous/suspected-foreign-body#pathway.
11. Kaiser CW, Slowick T, Spurling KP, Friedman S. Retained foreign bodies. J Trauma, 1997; 43 [1]: 107-111.
12. Courter BJ. Radiographic screening for glass foreign bodies - what does a "negative" foreign body series really mean? Ann Emerg Med, 1990; 19 [9]: 997-1000.
13. Arbona N, Jedrzynski M, Frankfather R, Lo AE, Hetman J, Mendicino SS, Rockett MS. Is glass visible on plain radiographs? A cadaver study. J Foot Ankle Surg, 1999; 38 [4]: 264-270.
14. Russell RC, Williamson DA, Sullivan JW, Suchy H, Suliman O. Detection of foreign bodies in the hand. J Hand Surg Am, 1991; 16 [1]: 2-11.
15. Körner M, Weber CH, Wirth S, Pfeifer KJ, Reiser MF, Treitl M. Advances in digital radiography: physical principles and system overview. RadioGraphics, 2007; 27 [3]: 675-686.
16. Cowen AR, Kengyelics SM, Davies AG. Solid-state, flat-panel, digital radiography detectors and their physical imaging characteristics. Clin Radiol, 2008; 63 [5]: 487-498.
17. Alsleem H, Davidson R. Radiographers' ability to detect low-contrast detail in digital radiography systems. Radiol Technol, 2015; 87 [1]: 29-37.
18. Reiner B, Siegel E, McLaurin T, Pomerantz S, Allman R, Hebel JR, Fritz S, Protopapas Z. Evaluation of soft-tissue foreign bodies: comparing conventional plain film radiography, computed radiography printed on film, and computed radiography displayed on a computer workstation. Am J Roentgenol, 1996; 167 [1]: 141-144.
19. Roobottom CA, Weston MJ. The detection of foreign bodies in soft tissue - comparison of conventional and digital radiography. Clin Radiol, 1994; 49 [5]: 330-332.
20. Hunter TB, Taljanovic MS. Foreign bodies. RadioGraphics, 2003; 23: 731-757.
21. Canon Medical Systems. CXDI-70C wireless premium flat panel detector. Irvine, CA: Canon Medical Systems; 2011.
22. Agfa HealthCare NV. CR 30-X digitizer. Mortsel: Agfa HealthCare NV; 2009.
23. Doyle P, Martin CJ, Gentle D. Application of contrast-to-noise ratio in optimizing beam quality for digital chest radiography: comparison of experimental measurements and theoretical simulations. Phys Med Biol, 2006; 51: 2953-2970.
24. Einarsdóttir H, Emerson MJ, Clemmensen LH, Scherer K, Willer K, Bech M, Larsen R, Ersbøll BK, Pfeiffer F. Novelty detection of foreign objects in food using multi-modal x-ray imaging. Food Control, 2016; 67: 39-47.
25. Mraity HA, England A, Cassidy S, Eachus P, Dominguez A, Hogg P. Development and validation of a visual grading scale for assessing image quality of AP pelvis radio-

graphic images. Br J Radiol, 2016; 89 [1061]: 20150430.

26. Norweck JT, Seibert JA, Andriole KP, Clunie DA, Curran BH, Flynn MJ, Krupinski E, Lieto RP, Peck DJ, Mian TA. ACR-AAPM-SIIM technical standard for electronic practice of medical imaging. J Digit Imaging, 2013; 26 [1]: 38-52.
27. Cicchetti DV. Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. Psychol Assess, 1994; 6 [4]: 284-290.
28. Jacobs SJ, Kuhl LA, Xu G, Powell R, Paterson DR, Ng CKC. Optimum tube voltage for pelvic direct radiography: a phantom study. The South African Radiographer, 2015; 53 [2]: 15-19.
29. Agfa HealthCare NV. Healthcare transformation, we'll take you ... there, 3rd ed. Mortsel: Agfa HealthCare NV; 2009.
30. Herrmann TL, Fauber TL, Gill J, Hoffman C, Orth DK, Peterson PA, Prouty RR, Woodward AP, Odle TG. Best practices in digital radiography. Albuquerque, NM: American Society of Radiologic Technologists; 2012.
31. Salazar AJ, Aguirre DA, Ocampo J, Camacho JC, Díaz XA. DICOM gray-scale standard display function: clinical diagnostic accuracy of chest radiography in medical-grade gray-scale and consumer-grade color displays. Am J Roentgenol, 2014; 202 [6]: 1272-1280.