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Diagnostic accuracy of radiographers' red dot usage in the emergency department

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ABSTRACT

Aim: To investigate the accuracy of radiographers applying the 'Red Dot System' after completing a 10-week online image interpretation course and whether observer confidence plays a role in diagnostic performance.
Materials and methods: Eligible participating radiographers undertook diagnostic accuracy testing. Tests involved a review of an anonymised historic trauma image set, and participants were asked to apply a 'red dot' to study radiographs if a radiographic pathology was evident. The diagnostic accuracy of radiographers' red dot ability was evaluated by generating a sensitivity, specificity and accuracy score for each participant. A Receiver Operating Curve (ROC) was also compiled to evaluate the participants' ability and confidence in discriminating the presence or absence of pathology.
Results: A total of 700 cases were analysed. Fourteen participating radiographers had an overall red dot (case-based) sensitivity, specificity and accuracy of 85%, 86% and 85%, respectively. Positive and negative predictive values (PPV/NPV) were both 86%. Radiographers' pathology-based sensitivity, specificity, and accuracy were 87%, 79%, and 83%, respectively. A resultant ROC curve generated an Area Under the Curve (AUC) value of 0.7.
Conclusion: Compared to the literature, participating radiographers' red dot skills could be considered acceptable but would benefit from improvement. We recommend that future work be carried out whereby participants at the study institution engage in a period of self-audit of their red dot practice and undertake additional diagnostic accuracy tests.

1. Introduction

The Red Dot System is a type of Radiographer Abnormality Detection System (RADS). Within RADS, a radiographer places a 'red dot' on a radiograph that is perceived to be abnormal during the post-processing stage of the examination. The system's primary function in practice is to notify the referring physician of the presence of acute or chronic pathology or occult fractures before the availability of the formal radiologist's report (Loughran, 1994).

Since its implementation in the United Kingdom (UK) during the 1980s, the Red Dot System has become widely adopted. Approximately 81% of UK hospitals have incorporated the system into their protocol (Price & Le Masurier, 2007). Additionally, UK research suggests that implementing the red dot into practice has positively impacted patient management in Emergency Departments (ED) (Hall, Egan, & Kleeman, 1999). A UK study revealed that radiographers' overall reporting accuracy is comparable to practising radiologists (Brealey, Scally, et al., 2005). Further research suggests that following a period of formal training, radiographers have an overall sensitivity of 92–97% and a specificity of 92–94% (Piper, Paterson, & Godfrey, 2005), with another paper concluding that when radiographers underwent formal red dot training, their image interpretation skills significantly improved from 90% to 93% (Hargreaves & Mackay, 2003).

Junior doctors within the Irish healthcare system primarily manage patient care in the ED despite having limited experience interpreting radiographs (Berman et al., 1985). Diagnostic errors have been shown to

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occur given the absence of a formal red dot system within the Irish healthcare system (Guly, 1984). Research suggests that reporting radiographs during on-call hours would significantly reduce the prevalence of diagnostic errors. However, the availability of a reporting radiographer in the ED is currently not standard practice (Hardy & Culpan, 2007). While not currently practised within the Irish healthcare system, research suggests that consistent use of the system nationally could pave the way for providing advanced radiographer practitioner roles (Brealey, King, Hahn, et al, 2005). This could ensure that the ever-increasing service demands of the Irish healthcare system are met (Brealey et al., 2006). As such, the current study aimed to evaluate the clinical accuracy of Irish radiographers' radiographic abnormality detection skillset, thereby adding to the existing evidence surrounding the topic.

2. Materials and Methods

2.1. Study design

This study employed a cross-sectional quantitative method. An anonymised historic radiographic image bank with known truth was used to train and assess the radiographer's red dot performance.

2.2. Study sample

Eligible study participants included qualified radiographers (~70) who had undertaken clinical practice at the study site, provided consent, and completed an image interpretation training course (10 × 1.0 h of online training). Participants were not excluded based on age, gender, race, or clinical experience. The anonymised historic image bank comprised 50 reported trauma/suspected foreign body radiographs (upper limb = 25, lower limb = 17, pelvis/spine = 6 and abdomen/chest = 2). In contrast, skull and facial bone radiographs were excluded. All radiographs included in the image bank had received prior ethical approval and had a formal radiology report issued by a consultant radiologist available.

2.3. Study setting

The study was conducted in a large teaching hospital where participants undertook a diagnostic accuracy test under the same conditions, such as room, room lighting, screen display and screen quality. The controlled conditions included a 3-megapixel Barco (Barco NV, Kortrijk, Belgium) Z440 landscape diagnostic screen display and a 2048 × 1536 monitor calibrated annually. These controlled conditions were used to review the test bank of trauma radiographs for the diagnostic accuracy test.

2.4. Study outcome

The primary outcome was the overall diagnostic accuracy of radiographers' abnormality detection skills concerning their red dot usage in detecting occult fractures/pathology.

2.5. Data collection

Data collected for this study were primarily quantitative. Data were collected using a baseline participant diagnostic accuracy test. An anonymised historic image set was used for the baseline diagnostic accuracy test. Before undertaking the test, participants were required to provide written consent. Participants viewed the study radiographs on a hospital site PC as part of the test and recorded their answers on provided paper-based data collection forms. Participants answered 'yes' if the participant detected a radiographic abnormality and wanted to red dot the image. They answered 'no' if they did not detect a radiographic abnormality and did not want to apply a red dot to the image under review. If participants applied a red dot to an image, participants were required to state the anatomical location. Participants provided a confidence rating ranging from 1 to 5 for each radiograph, 5 indicating greatest participant confidence and 1 indicating least participant confidence. The anonymisation process included the provision of a unique participant code/identifier for each study participant. Participants signed consent forms, and answer sheets were stored on a collaborative supported cloud storage platform whereby access was limited. Consent forms and answer sheets were shredded and disposed of securely following data transcription. Participants received feedback concerning their diagnostic accuracy test scores and whether their red dot accuracy skillset required improvement following the completion of the study.

2.6. Ethics

The study received research ethics committee approval from University College Cork.

2.7. Data analysis

Data analysis was undertaken using the software packages SPSS Version 23 (IBM Inc, Armonk, NY), MS Excel (Microsoft Corp, Redmond, WA) spreadsheet and Johns Hopkins Receiving Operating Curve (ROC) Analysis (Eng, 2017), an online ROC curve calculator (www.jrocfit.org). The diagnostic accuracy of radiographers' pathology detection skills, in the form of accurate application of a 'Red Dot,' was tested by running sensitivity, specificity and accuracy statistics for each participant. A positive rate was generated to assess the percentage of radiographers accurately detected radiographic abnormalities. An actual negative rate was also generated to determine the percentage of participants who accurately identified the absence of radiographic pathology. A crosstab was undertaken to assess true positives, false positives, true negatives, and false negatives. A ROC curve was carried out to investigate participants' ability and confidence in discriminating for the presence or absence of fractures, dislocations, and foreign bodies. The Area Under the Curve (AUC) value was used to evaluate the model's performance under study.

3. Results

3.1. Accuracy of radiographers

The average number of years of clinical experience was 5.4 (standard deviation = 3.4). Five participants had 2.5 years or less clinical experience, four had four to seven years of experience, and four had nine years or more experience. Of the 14 participants in this study, 50% had undergone a prior image interpretation course alongside the 12-week one. Table 1 reports the participants' accuracy in identifying abnormality present in the image. Radiographers' overall sensitivity in determining the presence of radiographic pathologies was 85% (76%–100%), with a mean sensitivity of 85.4%. The specificity of radiographers was 86% (72%–100%), with a mean sensitivity of 86.3% (Table 1). Our results showed that the overall positive and negative predictive values (PPV/NPV) were similar at 86% (Table 1).

Table 2 represents the participants' sensitivity in identifying the presence and anatomical location of the radiographic pathology. Radiographers' overall sensitivity in determining the presence of radiographic pathologies was 84%. Individual sensitivity ranged from 58% to 92%, respectively, with a mean sensitivity of 84%. For our study, sensitivity is the proportion of radiographs where a pathology is present, and a study participant (i.e., the radiographer) detected a pathology as part of the Red Dot test. Radiographers' overall specificity in identifying the correct absence of radiographic pathologies was 78%. Individual specificity ranged from 68% to 96%, respectively, with a mean specificity of 82%. For this study, specificity is the proportion of radiographs where a radiographic pathology is absent.

Table 1
Participants' case-based results for identifying radiographic normality and abnormality.

Participant	True Positive	True Negative	False Positive	False Negative	Positive predictive value (PPV) (%)	Negative predictive value (NPV) (%)	Sensitivity (%)	Specificity (%)	Accuracy (%)
P01	25	20	5	0	83	100	100	80	90
P02	21	20	5	4	81	83	84	80	82
P03	22	21	4	3	85	88	88	84	86
P04	21	23	3	3	88	88	87.5	88	88
P05	21	21	4	4	84	84	84	84	84
P06	19	24	1	6	95	80	76	96	86
P07	20	20	5	5	80	80	80	80	80
P08	21	21	4	4	84	84	84	84	84
P09	21	23	2	4	91	85	84	92	88
P10	21	20	5	4	80	83	84	80	82
P11	20	24	1	5	95	83	80	96	88
P12	23	18	7	2	76	90	92	72	82
P13	22	25	0	3	100	89	88	100	94
P14	21	23	2	4	91	85	84	92	88
Overall total	298	303	48	51	86	86	85	86	86
Mean (95% CI)					86.6 (83–90.3)	85.9 (83.2–88.4)	85.4 (82.4–88.4)	86.3 (82.2–90.5)	85.9 (83.9–87.9)
Standard Deviation					6.91	5.10	5.77	7.96	3.80

Table 2
Participants' pathology-based results for identifying radiographic normality and abnormality location.

Participant	True Positive	True Negative	False Positive	False Negative	Sensitivity (%)	Specificity (%)	Accuracy %
P01	23	21	6	0	100	77	0.88
P02	18	19	10	3	83	73	0.74
P03	20	20	9	1	95	69	0.80
P04	17	23	7	3	85	77	0.80
P05	21	20	7	2	91	74	0.82
P06	22	20	5	3	88	80	0.84
P07	19	21	8	2	90	72	0.80
P08	18	22	7	3	86	76	0.80
P09	20	25	1	4	83	96	0.90
P10	17	21	8	4	81	72	0.76
P11	20	24	1	4	83	96	0.90
P12	21	19	9	1	95	68	0.80
P13	21	25	1	3	88	95	0.92
P14	16	25	5	4	80	83	0.82
Overall	273	305	84	37	88	78	83
Mean (95%CI)					87.7 (84.6–90.8)	79.1 (74–84.3)	83.0 (80–86)
Standard Deviation					5.92	9.80	0.05

3.2. Confidence rating

The ROC curve generated, as seen in Fig. 1, graphically plots the true positive fraction (TPF) against the false positive fraction (FPF) for participants' confidence rating for each case. The area measured the accuracy of the test under the curve value for the ROC curve, which equalled 0.7. This indicates that the study participants performed acceptably in discriminating the presence or absence of radiographic lesions/pathologies. A standard error of 0.03 suggests that the data spread is small; therefore, there is a greater likelihood that the sample mean is close to the population mean.

3.3. ROC and AUC analysis

Table 3a, 3b shows the coordinates of the ROC curve response data and participant confidence rating (Brealey, Scally, et al., 2005; Hall et al., 1999; Loughran, 1994; Piper et al., 2005; Price & Le Masurier, 2007) along with TPF against the FPF calculation. Categorical rating data was collected in five categories, with category five representing the most substantial evidence of participant confidence (e.g., the abnormality is present) and category one representing the weakest evidence of participant confidence (e.g., the abnormality is not present). A total of 700 cases were analysed, with the ratio of positive to negative cases 50:50. Study data shows that participant confidence ratings varied. Participants were more confident in reviewing positive cases than negative cases as (320/350) 91% of positive cases received a ranking of 4 or 5, whereas (283/350) 80% received a ranking of 4 or 5.

4. Discussion

Due to the lack of currently available research on Irish radiographers' red dot usage, this project aimed to build on the existing findings surrounding the clinical accuracy of the red dot system. Data captured in this paper provides a baseline on the radiographers' overall accuracy in applying the Red Dot system. The present study established the performance of the red dot system in a sample of 50 trauma radiographs, with an 85% sensitivity and an 86% specificity, before undergoing a period of self-audit. Study participants' Red Dot sensitivity and specificity were not dissimilar to previous studies, with one study revealing that participants had an 87% sensitivity and 92% specificity (Brealey et al., 2006). This strengthens the external validity and generalizability of the study. However, we must acknowledge that the Red Dot practice at the study site is currently performed voluntarily. Therefore, the accuracy of the study participants' Red Dot skills reflects the accuracy of a non-mandatory practice. If enforced, it would give a true reflection of the radiographer's ability.

In the context of RADS, this study represents a novel exploration of radiographers' diagnostic accuracy skillset. It captured data relating to

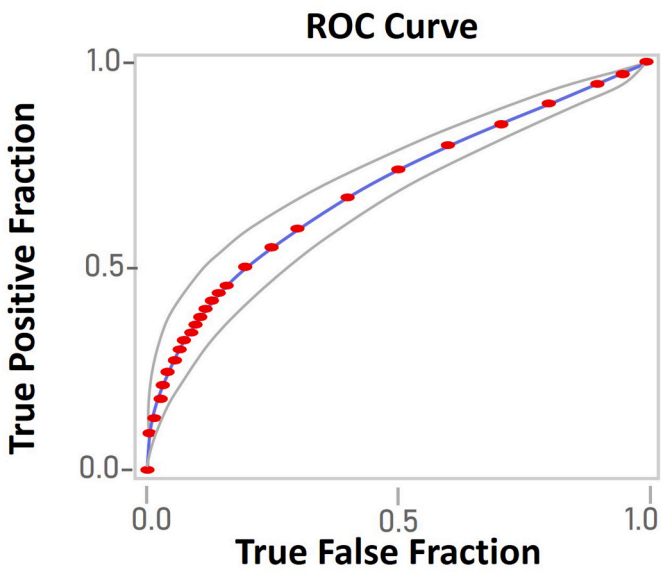

Fig. 1. ROC Curve plotting the TPF against the FPF and highlighting the area under the curve as 0.7. (SD 0.025). Red dots are individual data points, the blue line is the ROC curve, and the grey lines are the 95%CI of the ROC curve. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3a
Participant Confidence Rating (Brealey, Scally, et al., 2005; Hall et al., 1999; Loughran, 1994; Piper et al., 2005; Price & Le Masurier, 2007) and FPF and TPF calculation.

Category	1	2	3	4	5	Total
Negative Cases	0	5	62	129	154	**350**
Positive Cases	1	4	25	77	243	**350**

TPF = true positive fraction; FPF = false positive fraction.

Table 3b
Receiver operator characteristic (ROC) curve response data.

FPF (x-axis)	0	0.440	0.809	0.986	1.000	1.000	AUC (SD)
TPF (y-axis)	0	0.694	0.914	0.986	0.997	1.000	0.7 (0.025)

TPF = true positive fraction; FPF = false positive fraction; AUC=Area Under the Curve; SD=Standard deviation.

radiographers' red dot application and the study participants' sensitivity in detecting lesions and specificity in identifying anatomical locations of perceived pathology. The sensitivity and specificity scores of the participants studied ranged from 81-100% to 68–96%, respectively. Significant variance is evident in relation to radiographers' Red Dot skillset. Questions may arise about the comparability of findings with radiologists. Research suggests that consultant radiologists have an accuracy of 98% sensitivity and 98% specificity (Tachakra, Mukherjee, Smith, & Dutton, 2002). There is a significant difference between the diagnostic accuracy of consultant radiologists and that of the radiographers who participated in this study. This begs the question, why the difference? As the study viewing conditions for this study were like that of a radiologist's office in terms of lightning and the screen monitor used, extrinsic predictors such as radiographer clinical experience and last red dot and educational experience may have influenced this degree of variance in terms of study participants' overall accuracy.

Participant demographic data captured participants' years of clinical experience and prior experience undertaking a Red Dot course. Participants clinical experience varied, with some radiographers having as little as one year of experience and others having up to 11 years. Only 50% of participants stated not having undertaken a prior Red Dot training. Participant sensitivity and specificity accuracy scores varied; thus, participants' level of education may have affected participants' overall accuracy scores. Such findings align with current research suggesting that clinical experience, abnormality detection accuracy, and speed are correlated (Wood et al., 2013).

This study captured participants' confidence levels in reviewing 'abnormal' (where pathology was evident) and 'normal' (where pathology was not apparent) radiographs. Study participants were found to have greater confidence in analysing and interpreting study radiographs classified as 'abnormal' compared to 'normal', with 91% of 'abnormal' radiographs receiving a confidence rating of 4 or 5 and 80% of 'normal' radiographs receiving a confidence rating of 4 or 5. Participant clinical experience may have played a role in the variation of these results. Similarly, research suggests that non-reporting radiographers report greater confidence levels in detecting radiographic abnormalities than in describing radiographic abnormalities (Neep, Steffens, Owen, & McPhail, 2014). Previous studies have concluded that radiographers demonstrate more confidence and accuracy in interpreting radiographs upon completing formal image interpretation and Red Dot training (Mackay, 2006). As experienced radiographers may possess a breadth of knowledge gained throughout their clinical experience, their confidence level to practice the Red Dot system formally may vary. Such findings provide a strong foundation for implementing Red Dot training at undergraduate and postgraduate levels and as part of Continuing Professional Development (CPD) education.

4.1. Economic analysis

The Radiographer Red Dot system exemplifies the principle of comparative advantage in healthcare. Harnessing the unique competencies of radiographers in image evaluation allows them to handle preliminary image assessments, thereby freeing radiologists to focus on more intricate and complex diagnoses. This division of labour ensures that each professional operates in their expertise, maximising efficiency with high-quality patient care (Saldana et al., 2022).

From an economic standpoint, the system introduces potential cost savings without compromising on the quality of service. Using an underestimated but standardised economic metric of a 10-s evaluation for the 700 cases mentioned, the Red Dot system's projected annual cost to the Irish Health Service Executive (HSE) would amount to €227 for a senior radiographer (1 WTE @ €60,250 per annum grade 5). In contrast, the cost for a radiologist would be €600 (1 WTE @ €159,128 per annum). This translates to a €373 opportunity cost saving. However, it is essential to account for the variability in case complexity. Not every instance will demand a 10-s evaluation, typically much more. Incorporating this variability ensures a more realistic estimation of the system's economic viability (Riewpaiboon, 2014).

The Radiographer Red Dot system presents a compelling case for healthcare efficiency and cost-effectiveness. The system's implementation, by allowing radiographers to handle preliminary image assessments, optimises the allocation of resources. This redirection of the radiologists' workflow will enable them to substitute their time more effectively, focusing on intricate diagnoses and reducing anchoring bias and judgment error. Our study also emphasises the importance of transparent economic evaluations in implementation science, highlighting the need for clear cost and outcome assessments for decision-makers. When evaluated using the Consolidated Health Economic Evaluation Reporting Standards, the Red Dot system showcases its potential for significant cost savings without compromising service quality. Riewpaiboon and colleagues (2014) highlight the importance of accurate cost measurement in health economic evaluations. This suggests the Red Dot system's cost-effectiveness can be more precisely gauged by incorporating such methodologies (Riewpaiboon, 2014).

Furthermore, the system's economic viability extends beyond mere cost savings. The enhanced role of radiographers can improve

recruitment and retention rates, offering long-term economic benefits by mitigating the financial challenges associated with high turnover (Barnett et al., 2014). However, the journey to realising these economic benefits is not devoid of challenges. Issues such as professional protectionism, resistance from radiologists, and the absence of formal training opportunities can pose significant roadblocks. Yet, these challenges can be surmounted with strategic investments in training and fostering a culture that emphasises teamwork.

In essence, the Red Dot system, when viewed through an economic lens, represents a strategic investment in healthcare efficiency. Through collaborative synergy, it capitalises on the specialised assets of radiographers and radiologists, yielding a higher return on investment in healthcare outcomes and cost savings. As both professionals utilise their distinct yet equally valuable expertise, especially within the Red Dot framework, there is an increase in marginal productivity. This surge in efficiency translates to a higher probability of achieving optimal health outcomes. Over time, this collaborative model demonstrates the economic concept of increasing returns to scale, where the combined output of radiographers and radiologists, working in tandem, exceeds the sum of their outputs.

Study findings suggest that the cohort of radiographers can perform to a good, acceptable diagnostic standard, with an AUC of 0.70. International standards suggest that an AUC of 0.90, close to 1, indicates an almost perfect test in relation to diagnostic performance, whereas an AUC close to 0.5 indicates poor test and diagnostic performance (Wood et al., 2013). This shows that study participants performed acceptably in discriminating for the presence or absence of radiographic lesions. It is important to note that there was a large variance in participants' sensitivity in lesion detection, with one participant having a sensitivity of 92% and another having a sensitivity of 58%. Additionally, no study participant scored greater than 95% in relation to their diagnostic performance in discriminating for the presence or absence of radiographic lesions. As a result, improvement in terms of participants' diagnostic performance is warranted and encouraged.

This study is subject to certain limitations. While the original methodology aimed to assess the overall accuracy of study participants in pre- and post-intervention phases, baseline data was obtained due to logistical constraints related to participant availability for self-audit interventions and post-diagnostic accuracy tests. The absence of a self-audit intervention hindered the acquisition of pre- and post-intervention data. We propose that radiographer performance undergo regular re-evaluation, in line with recommendations advocating periodic self-assessment to enhance image interpretation analysis practice (Neep et al., 2014). Furthermore, it is pertinent to acknowledge that this study featured a sample size of only fourteen individuals; therefore, caution must be exercised in generalising these findings to the broader Irish radiography profession.

While this study has some limitations, it provides baseline information regarding radiographers' accuracy in interpreting trauma radiographs and provides a platform for future research. It is important to note that implementing a red dot only on a radiograph is ineffective without identifying or labelling a potential abnormality, as it might sometimes be confusing for clinicians to localise the abnormality by themselves. Also, there can be an element of bias when the system identifies an incorrect or clinically irrelevant abnormality. Therefore, strict auditing and scrutiny for this system is necessary, and only trained and experienced radiographers should be involved.

5. Conclusion

In our study, participating radiographers' red dot skillset, compared to the literature, could be considered acceptable but would still benefit from improvement. We recommend future work to capture post-intervention data following a period of self-audit. Together with this study, such findings may provide a solid basis to help promote image interpretation training not only at an institutional level but also at a national level, thereby paving the way for the future implementation of a national RADS protocol roll-out in Ireland.

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Declaration of competing interest

None.

References

Barnett, J. H., Lewis, L., Blackwell, A. D., et al. (2014). Early intervention in Alzheimer's disease: A health economic study of the effects of diagnostic timing. *BMC Neurology, 14*, 101. https://doi.org/10.1186/1471-2377-14-101

Berman, L., de Lacey, G., Twomey, E., Twomey, B., Welch, T., & Eban, R. (1985). Reducing errors in the accident department: A simple method using radiographers. *Br Med J (Clin Res Ed)., 290*(6466), 421–422.

Brealey, S., King, D., Hahn, S., et al. (2005). The costs and effects of introducing selectively trained radiographers to an A&E reporting service: A retrospective controlled before and after study. *The British journal of radiology, 78*(930), 499–505.

Brealey, S., Scally, A., Hahn, S., Thomas, N., Godfrey, C., & Coomarasamy, A. (2005). Accuracy of radiographer plain radiograph reporting in clinical practice: A meta-analysis. *Clinical Radiology, 60*(2), 232–241.

Brealey, S., Scally, A., Hahn, S., Thomas, N., Godfrey, C., & Crane, S. (2006). Accuracy of radiographers red dot or triage of accident and emergency radiographs in clinical practice: A systematic review. *Clinical Radiology, 61*(7), 604–615.

Eng, J. (2017). *ROC analysis: Web-based calculator for ROC curves*. Baltimore: Johns Hopkins University. Updated 2014 March 19. Accessed 25/05/17. Available from: http://www.jrocfit.org.

Guly, H. R. (1984). Missed diagnoses in an accident & emergency department. *Injury, 15*(6), 403–406.

Hall, R., Egan, I., & Kleeman, S. (1999). The red dot system: The outback experience. *The Radiographer: The Official Journal of the Australian Institute of Radiography, The, 46*(2).

Hardy, M., & Culpan, G. (2007). Accident and emergency radiography: A comparison of radiographer commenting and 'red dotting'. *Radiography, 13*(1), 65–71.

Hargreaves, J., & Mackay, S. (2003). The accuracy of the red dot system: Can it improve with training? *Radiography, 9*(4), 283–289.

Loughran, C. F. (1994). Reporting of fracture radiographs by radiographers: The impact of a training programme. *British Journal of Radiology, 67*(802), 945–950.

Mackay, S. (2006). The impact of a short course of study on the performance of radiographers when highlighting fractures on trauma radiographs:"The Red Dot System". *The British journal of radiology, 79*(942), 468–472.

Neep, M. J., Steffens, T., Owen, R., & McPhail, S. M. (2014). A survey of radiographers' confidence and self-perceived accuracy in frontline image interpretation and their continuing educational preferences. *Journal of Medical Radiation Sciences, 61*(2), 69–77.

Piper, K., Paterson, A., & Godfrey, R. (2005). Accuracy of radiographers' reports in the interpretation of radiographic examinations of the skeletal system: A review of 6796 cases. *Radiography, 11*(1), 27–34.

Price, R. C., & Le Masurier, S. B. (2007). Longitudinal changes in extended roles in radiography: A new perspective. *Radiography, 13*(1), 18–29.

Riewpaiboon, A. (2014). Measurement of costs for health economic evaluation. *Journal of the Medical Association of Thailand, 97*(Suppl 5), S17–S26.

Saldana, L., Ritzwoller, D. P., Campbell, M., et al. (2022). Using economic evaluations in implementation science to increase transparency in costs and outcomes for organisational decision-makers. *Implementation Science Communication, 3*, 40. https://doi.org/10.1186/s43058-022-00295-1

Tachakra, S., Mukherjee, P., Smith, C., & Dutton, D. (2002). Are accident and emergency consultants as accurate as consultant radiologists in interpreting plain skeletal radiographs taken at a minor injury unit? *European Journal of Emergency Medicine, 9*(2), 131–134.

Wood, G., Knapp, K. M., Rock, B., Cousens, C., Roobottom, C., & Wilson, M. R. (2013). Visual expertise in detecting and diagnosing skeletal fractures. *Skeletal Radiology, 42*(2), 165–172.