Radiography 25 (2019) 255–259

Contents lists available at ScienceDirect

Radiography

journal homepage: www.elsevier.com/locate/radi

# Accuracy of appendicular radiographic image interpretation by radiographers and junior doctors in Ghana: Can this be improved by training?

B.B. Ofori-Manteaw [a, *], E. Dzidzornu [b]

[a] Radiology Department, Effia-Nkwanta Regional Hospital, Box 229, Sekondi-Takoradi, Ghana
[b] School of Allied Health Sciences, University of Health and Allied Sciences, Ho, Ghana

ARTICLE INFO

*Article history:*
Received 27 September 2018
Received in revised form
10 March 2019
Accepted 6 April 2019
Available online 18 April 2019

*Keywords:*
Radiographers
Junior doctors
Appendicular skeleton
Image interpretation

ABSTRACT

*Introduction:* Access to image interpretation in Ghana remains a challenge with the limited number of radiologists. Radiographers with the right skills and knowledge in image interpretation could help address this challenge. The aims of the study were to determine and compare the ability (accuracy, sensitivity and specificity) of radiographers and junior doctors in interpreting appendicular trauma radiographs both before and after training.

*Methods:* An action research study involving a pre and post training test was carried out to determine the level of accuracy, sensitivity and specificity in abnormality detection by radiographers after undergoing training when compared to junior doctors. Eight radiographers and twelve junior doctors were invited to interpret an image bank of 30 skeletal radiographs, both before and upon completion of an educational program. The participants' tests were scored against a reference standard provided by an experienced radiologist. Pre and post-test analysis were carried out for comparison.

*Results:* Post training mean accuracy (radiographers 83.3% vs 68.8%, $p = 0.017$; doctors 81.9% vs 71.6%, $p = 0.003$), sensitivity (radiographers 83.3% vs 69.2%, $p = 0.042$; doctors 77.2% vs 67.8% $p = 0.025$) and specificity (radiographers 83.3% vs 68.3%, $p = 0.011$; doctors 86.7% vs 75.6% $p = 0.005$) of both groups significantly improved. No significant differences were recorded between the radiographers and doctors after the training event.

*Conclusion:* The study revealed that, with a well-structured training program, radiographers and junior doctors could improve on their accuracies in radiographic abnormality detection and commenting on trauma radiographs.



## Introduction

Accurate and timely interpretation of radiographs is important in making informed decisions in the diagnosis and management of patients. Any delay in accessing radiological reports could affect both the clinician's management and patient's outcome. The shortage of radiologists[1] in several countries has led to radiographers extending their roles in image interpretation. Ghana has a radiologist to population ratio of 1:350,000[2] and access to image interpretation remains a challenge. Radiographers extending their roles in image interpretation could therefore help address this challenge. Image interpretation by radiographers has gone through several stages over the years. The "red dot" scheme which was the first level of image interpretation[3,4] among radiographers served as a means for radiographers to notify clinicians the presence of any abnormality on an X-ray.[5,6] However, the "red dot" scheme restricted radiographers from specifying and describing the location and nature of an abnormality.[7] The second level of image interpretation is the radiographer commenting scheme which involves the ability of radiographers to identify and describe abnormalities on radiographs,[3] and was introduced as a result of the limitations associated with the "red dot" scheme.[5,6] Though the frontline role of radiographers in commenting on radiographs could improve their job satisfaction and professional standing,[8] it could also be cost effective. While the "red dot" scheme limited the radiographer in communicating an opinion to the healthcare

* Corresponding author.
*E-mail addresses:* levelgee2005@yahoo.com (B.B. Ofori-Manteaw), edzidzornu2018@sahs.uhas.edu.gh (E. Dzidzornu).

https://doi.org/10.1016/j.radi.2019.04.003
1078-8174/

team,[3] the commenting scheme gives opportunity to describe the appearance and location of any perceived abnormality.[3,5,6] This helps reduce the time and stress required by referring clinicians in searching for abnormalities associated with a "red dot". Though the provision of initial accurate written comments for Accident and Emergency (A & E) radiographs could improve the overall turn-around time required by clinicians to make decisions,[9,5,10] it could only be achieved when radiographers acquire the appropriate training. Several studies[6,10–13] have reported increase in accuracies, sensitivities and specificities among radiographers who engaged in written commenting on radiographs in the A & E after receiving training. In a comparative study by Piper and Paterson[12] among radiographers and nurses on commenting of trauma radiographs, both groups recorded an increase in sensitivity and specificity following training. Though an earlier study by Atta-Boateng[14] revealed the willingness of Ghanaian radiographers to extend their roles in film interpretation, the study failed to assess the image interpretation abilities of the radiographers. This study therefore sought to assess the impact of an educational training on the film interpretation abilities of radiographers in Ghana. The third level of image interpretation is the radiographer reporting scheme which involves radiographers who have completed high level postgraduate education and are able to independently issue formal written reports similar to radiologists.[3,5,15,16]

### *Aims*

The aims of this study were to determine and compare the ability (accuracy, sensitivity & specificity) of radiographers and junior doctors in interpreting appendicular trauma radiographs both before and after training.

## Methods

### *Research design*

An action research study was conducted since the project aim was to implement and assess the potential for a change in current practice including pre and post-implementation training. Action research seeks to cause a change by generating new methods or ideas[17] in a way to improve current practice.[18]

### *Ethical considerations*

Appropriate approval for the study was gained from the Sheffield Hallam University Research Ethics Committee and the Ghana Health Service Ethics Committee (GHS-ERC:11/02/2017).

### *Recruitment*

A convenient group of eight (8) radiographers and twelve (12) junior doctors were available at the time of the study for participation in the study. Specialists, consultants and senior medical officers were excluded from the study because they may have acquired some form of experience in image interpretation in the course of their practice. It was explained to the participants that their participation in the study was voluntary. None of the twenty participants dropped out in the course of the study.

### *Selection of images*

Thirty (30) radiographic images of the appendicular skeleton following trauma were drawn from a pool of images from the image reader of the X-ray department of the study site. The images were spread between normal and abnormal with approximately a 50% split and had already been reported on by the consultant radiologist at the hospital. The reports of these images were retrieved from the computer archives to serve as reference point for comparison of results from the participants. Two normal variant images of the epiphyseal growth plates of the knee and elbow joints were included as part of the test content to test the ability of the participants in recognising epiphyseal lines.[7] Perceptual and cognitive errors are common cause of missed diagnosis in image interpretation.[19] Similarly, inaccurate diagnosis could also arise from the lack of more than one radiologist in reviewing radiological reports.[20] A previous study had reported of an inter-observer variation occurring in 10% of skeletal radiographs reported among consultant radiologists.[21] Inter-rater reliability is the extent to which more than one radiologist assigns the same report to the same diagnostic test.[22] It would have been ideal to have more than one radiologist in producing the study reference standard in other to ensure reproducibility of the reports. However, due to the lack of radiologists in the region, the researchers had to fall on the only consultant radiologist available. The consultant radiologist, having practiced for several years had a lot of experience to ensure reliability of the reports. Additional images of the appendicular skeleton following trauma were also printed in hard copy forms for the training program. The test images did not form part of the images for the training sessions in other to prevent recall bias.

### *Participant information sheets and consent forms*

Before the commencement of the study, each participant was issued an information sheet and consent form outlining the details of the study. It was clearly stated on the consent form that participation in the study was voluntary and that participants could withdraw from the study at any point in time. Each participant was provided with a specific code made available on the information sheet and the pre-test answer booklets. Participants were to provide the code on the answer booklet during the post training test to enable the researchers correlate the individuals' pre/post test scores. One professional group was coded with letters and the other with numbers. The test marker was also not privy to the difference between the coding of the groups in other to avoid marking bias. In the answer booklet, the participants were to specify how they perceived their ability to interpret radiographs in normal clinical practice using a scale of 1–10. A score of 1 represented 'not at all accurate' and a score of 10 represented 'very accurate'. No names were provided by participants in the course of data collection to ensure anonymity.

### *Pre and post training tests*

The selected images for the study were printed in hard copy forms since the participants viewed their X-ray images in hard copy forms in normal clinical practice. Proper viewing conditions are important when interpreting radiographs hence the test room was set up with room illumination at ambient light levels to reduce eye strain[23] and avoid image interpretation errors.[24] The viewing boxes had bright lights and spot viewing areas to aid in viewing subtle parts of any image. Magnifying aids were also made available at hand to help visualize less visible parts of any image. All the images were serialized with numbers from 1 to 30 to avoid mix-up and also for easy correlation with the corresponding clinical histories indicated in the answer booklets provided. The clinical history was based on the history stated on the X-ray request at the time of initial referral for the X-ray test.[10] Participants had to identify and state whether each image presented was normal or abnormal. For all images answered as abnormal, participants were to describe briefly the location and nature of abnormality. A maximum of

45 min was allocated for the session after which the booklets were collected. The allocated time was based on a previous study that allowed 150 min for 100 images (90 s per image).[7] The 45 min was also to enable participants have ample time to make informed decisions on the images presented and also to revisit any image that they were initially unsure of. Similarly, a guideline from the Royal College of Radiologists, United Kingdom recommends an approximately 90 s per examination in interpreting radiographic examinations.[21]

*Training sessions*

Participants underwent two training programmes in appendicular skeletal radiograph interpretation carried out by an experienced consultant radiologist across a period of 2 weeks. The training content was similar to what had been employed in a previous study by Hazell et al.[7] Attendance was taken to monitor that every participant was present for all training sessions and tests carried out.[7] The training programme involved an introduction to pattern recognition and its application to the appendicular skeleton. The lectures were a combination of Power-Point presentations and practical trainings. Lecture notes for the training program in the form of hard copy manuals were provided for each participant. Digital copies of the lecture notes and additional digital images with a variety of trauma abnormalities were also made available to the participants for individual use. Participants were taken through a checklist containing a systematic method of evaluating images for potential abnormalities. The participants were to use the checklist, skills and techniques acquired to interpret images during the post-test. Three days after the last training session, the participants were given the same image test bank used for the pre-test to interpret. The same steps for the pre-test were employed for the post-test. There was about a three week period between pre and post testing. Due to the low staffing strength of the departments and the busy work schedule of the participants, it was impossible to lengthen the study period. In addition, junior doctors as part of their housemanship training are periodically rotated to other district health facilities. Ideally, a larger time interval would be needed between pre-testing and post-testing as well as the last training session and post-testing in other to control memory effect. All the participants were present for both training sessions and were tested together for both pre and post training tests. The researchers supervised both tests to ensure that participants could not discuss and exchange answers.

*Test marking*

The information sheets were removed from the answer booklets before marking to ensure the scorer was blind to the profession of the individual participants.[10] The answered questions were marked by an experienced radiographer with over 30 years of clinical experience against the reference standard. The format of marking and scoring was based on similar format applied in previous studies.[10,25] An image correctly classified as normal or abnormal with correct location and description of abnormality was awarded a mark of 2. An image correctly identified as abnormal but with wrong identification of location and description of abnormality was awarded a mark of 1. A wrongful spelling attracted no penalty. A total score of 60 marks was therefore expected from each participant.

*Data analysis*

The data was entered into the statistical analysis software, Statistical Package for Social Sciences (SPSS version 22.0). Significance threshold was taken at $p \leq 0.05$ as a general standard value in social science research.[26] The individuals' performances were rated as true positive, false positive, true negative or false negative from which the individuals' accuracy, sensitivity and specificity were computed. The data was analyzed for normality using the Kolmogorov–Smirnov statistic and found not to be normally distributed. The mean performances of both groups were calculated for the pre- and post-tests (Table 1). The Wilcoxon signed ranks test was used to compare the pre and post-test performances of each group. The Mann–Whitney (U) independent sample test statistics was performed to test for equality between the tests results of both groups.

## Results

The radiographers and junior doctors had work experience ranging from less than a year to ten years and less than a year to two years respectively. Two radiographers had practiced for less than a year and five had practiced between 1 and 5 years. One radiographer had also worked between 6 and 10 years. Five of the doctors had between 1 and 2 years of post-registration clinical experience. Three doctors had practiced for less than 6 months and four had between 6 and 12 months of clinical experience. In addition, the majority of participants (n = 18) had experience of A & E cases.

The Pearson's Correlation Coefficient was used to evaluate the relationship between the participants' perceived image interpretation accuracy prior to the start of the study and the actual accuracy of their pre-test. Both radiographers and doctors demonstrated mild positive correlations (r = 0.2, p = 0.635) and (r = 0.40, p = 0.197) respectively but were not statistically significant. Post-training mean test scores among radiographers significantly improved by 14.5 (48.8 vs 34.3, p = 0.012). In addition, there were significant differences in the post-test mean sensitivity (83.3% vs 69.2%, p = 0.042), specificity (83.3% vs 68.3%, p = 0.011) and accuracy scores (83.3% vs 68.8%, p = 0.017). Similar trends were recorded among the doctors in terms of test scores (48.8% vs 37.3%, p = 0.002), sensitivity (77.2% vs 67.8% p = 0.025), specificity (86.7% vs 75.6% p = 0.005) and accuracy (81.9% vs 71.6% p = 0.003).

*Area under curve (AUC) performance*

The receiver operating characteristic curve analysis was used to assess the overall performance of both professional groups for the pre and post-tests. The AUC ranges from 0.0 to 1.0. Statistically significant higher mean post-test AUC values (0.83 vs 0.7, p = 0.017; 0.82 vs 0.72, p = 0.003) were recorded among the radiographers and doctors respectively compared to their pre-test performances. There was no significant difference between the post-test mean AUC values (0.83 vs 0.82, p = 0.343) of radiographers and doctors.

**Table 1**
Wilcoxon signed ranks test (z) analysis for the pre and post test results.

| | Pre test | Post test | z | p-value |
|---|---|---|---|---|
| **Radiographers** | | | | |
| Accuracy (SE) | 68.8% (4.3) | 83.3% (2.1) | −2.379 | 0.017 |
| Sensitivity | 69.2% | 83.3% | −2.035 | 0.042 |
| Specificity | 68.3% | 83.3% | −2.539 | 0.011 |
| AUC | 0.70 | 0.83 | −2.388 | 0.017 |
| **Doctors** | | | | |
| Accuracy (SE) | 71.6% (2.3) | 81.9 (1.3) | −2.938 | 0.003 |
| Sensitivity | 67.8% | 77.2% | −2.239 | 0.025 |
| Specificity | 75.6% | 86.7% | −2.820 | 0.005 |
| AUC | 0.72 | 0.82 | −2.943 | 0.003 |

AUC: Area under curve SE: Standard Error.

*Comparative analysis of test results between radiographers and doctors*

The Mann–Whitney (U) independent sample test statistics was performed to test for equality between the tests results of both groups. No statistical differences were recorded when both groups were compared in terms of their corresponding pre and post test results (Table 2). The radiographers achieved higher abnormality detection rate (sensitivity) than the doctors in both pre and post-test analysis (pre-test, 69.2% vs 67.8% $p = 0.792$; post-test, 83.3% vs 77.2% $p = 0.135$) but statistically insignificant. The doctors on the other hand attained higher specificity scores than their counterpart radiographers (pre-test, 75.6% vs 68.3%, $p = 0.305$; post-test, 86.7% vs 83.3%, $p = 0.521$) but the differences were also not statistically significant. Also, though the doctors recorded a higher mean accuracy score than the radiographers in the pretest (71.6% vs 68.8%, $p = 0.734$), the opposite was observed for the radiographers in the post test analysis (83.3% vs 81.9%, $p = 0.343$) though the differences were again not statistically significant (Table 2).

## Discussion

Worldwide, there has been a paradigm shift in the interpretation of radiographs, with radiographers playing a frontline role in the commenting of radiographs.[6] However, in Ghana, most radiographers who engage in the interpretation of radiographs lack formal postgraduate training and do so unregulated. There is no formal postgraduate education in image interpretation for radiographers offered in any of the tertiary institutions in Ghana. Results from the study showed radiographers lacked perceived ability in recognizing and describing X-ray abnormalities following trauma prior to the training. Imaging pathology and pattern recognition among student radiographers is taught for one semester at the University which could be, arguably, inadequate for newly qualified radiographers to accurately interpret radiographs.[6] There are also the resistance from radiologists[14] and the general lack of acceptance of radiographers who engage in written comments on radiographs, which may have accounted for the low level of confidence ($r = 0.2$) recorded among the radiographers. The doctors however demonstrated a comparatively higher level of confidence ($r = 0.4$) than the radiographer in the interpretation of radiographs in clinical practice though statistically insignificant. Doctors receive clinical radiology training in the course of their study to diagnose at first instance and this could be a reason for the levels of confidence recorded. The willingness of radiologists to mentor radiographers would therefore be essential in improving the confidence levels, abnormality detection and description skills of radiographers.

**Table 2**
Independent samples Mann–Whitney (U) test between radiographers and junior doctors.

| | Radiographers | Junior Doctors | U | p-value |
|---|---|---|---|---|
| **Pre-test** | | | | |
| Accuracy (SE) | 68.8% (4.3) | 71.6% (2.3) | 53 | 0.734 |
| Sensitivity | 69.2% | 67.8% | 44 | 0.792 |
| Specificity | 68.3% | 75.6% | 62 | 0.305 |
| AUC | 0.70 | 0.72 | 53 | 0.734 |
| **Post-test** | | | | |
| Accuracy (SE) | 83.3% (2.1) | 81.9% (1.3) | 35 | 0.343 |
| Sensitivity | 83.3% | 77.2% | 28 | 0.135 |
| Specificity | 83.3% | 86.7% | 57 | 0.521 |
| AUC | 0.83 | 0.82 | 35 | 0.343 |

AUC: Area under curve SD: Standard error.

Post-training scores and values achieved by the radiographers and doctors were statistically higher than those demonstrated in their respective pre-test scores as outlined in Table 1. The significant increase in accuracy, sensitivity and specificity implies the educational intervention had a positive effect on both groups' ability to identify and describe traumatic appearances of the appendicular skeleton. This was consistent with findings from an earlier study[7] among South African radiographers. Furthermore, separate studies,[6,10,12,13,27] had all reported of high sensitivities and specificities among radiographers who engaged in written commenting on radiographs of the appendicular skeleton after undergoing training. Hence, a re-test without the training sessions may not have recorded any improved performances from the participants.[28] This presupposes that radiographers could improve on their image interpretation skills when given the required training. To the best of our knowledge, currently, there is no radiographer in Ghana with post graduate qualification in image interpretation. As such, radiographers who engage in image interpretation acquire their skills on-the-job either from senior colleagues or radiologists. It would therefore be prudent for radiographers to undergo regular educational trainings of this nature to complement their skills and knowledge.

Although post-training mean scores significantly improved by the radiographers and doctors, there were no significant variation when the test results of both groups were compared. This was however different from a similar study[10] among radiographers and other health professionals where significant variations in their test scores were recorded. This is because the institution lacked guidelines for radiographers and junior doctors seeking to engage in trauma radiograph interpretation. The non-availability of educational and mentoring programmes in place implies that radiographers and junior doctors are unable to improve on their image interpretation skills. It is therefore prudent that institutions seeking to implement the commenting scheme put in place guidelines to regulate its implementation. In terms of experience, results from the study showed a weak positive correlation between the years of work experience and the pre-test accuracy scores of radiographers ($r = 0.34$, $p = 0.40$) and doctors ($r = 0.22$, $p = 0.48$). Though doctors are trained to diagnose at first instance, the majority ($n = 7$) had worked for less than a year and may not have acquired enough experience to adequately interpret radiographs. Similarly, there is growing evidence to suggest the amount of radiology teaching in undergraduate medical school curricula are inadequate.[29–31] Moreover, there is no acceptable training structure in place for junior doctors and radiographers working within the hospital hence the weak correlation recorded. This implies that experience alone cannot be enough for accurate interpretation of radiographs. Combined regular educational trainings and constant skills practice could therefore be essential for accurate image interpretation among radiographers and doctors.

The diagnostic test accuracy (AUC) of both groups significantly improved after post training (Table 1). The AUC value ranges from 1- to 1 and a test is deemed very accurate when the AUC value is nearer to 1.0.[32] Though there were no significant variations in the mean AUC values of the radiographers and doctors, the mean post-test AUC values were closer to 1.0 indicating greater accuracy from the test. The high diagnostic test accuracies exhibited by both group further signifies the impact of the training programme on their abnormality detection abilities.

*Limitations and recommendations from the study*

Findings from the study, may not be a true representation of the image interpretation skills of the entire radiographers in Ghana due to the sample size used. The sample size of twenty participants (12

junior doctors, 8 radiographers) may have not enabled significant differences to be detected between the two groups. Similarly, the study was carried out in a single public health facility and the findings may not be generalized nationally. There was only one consultant radiologist and test scorer used in the study which could be a source of bias. It was important to have more than one radiologist and scorer in other to eliminate bias and ensure reproducibility of results.[22] There could also be the possibility of memory effect due to the about 3 week interval between the pre-test and post-test. The training programme was limited to the appendicular skeleton and did not investigate the cost implication of implementing such abnormality detection scheme. Subsequent studies could focus on other anatomical regions of interest and the cost implication in implementing such scheme.

## Conclusion

The study revealed an increase in accuracy, sensitivity, specificity and confidence levels among radiographers and junior doctors after a training event. The participants lacked confidence in recognising and describing trauma abnormalities prior to training. No significant variations were recorded between the radiographers' and junior doctors' trauma X-ray interpretation abilities. The outcome of the study indicated that the required training can improve initial levels of confidence and image interpretation skills in both radiographers and junior doctors in contributing to the clinical diagnosis and management of patients.

## Declarations of interest

None

## Conflicts of interest statement

None

## Acknowledgements

Our heart-felt appreciation goes to Dr Pauline Reeves and Mr Lawrence Arthur for their tremendous support and in-depth knowledge offered during each phase of the study.

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## References

1. Page BA, Bernoth M, Davidson R. Factors influencing the development and implementation of advanced radiographer practice in Australia - a qualitative study using an interpretative phenomenological approach. *J Med Radiat Sci* 2014;**61**(3):142–50. https://doi.org/10.1002/jmrs.62.
2. Sule D. *Radiographers' role extension: the way forward among Ghanaian radiographers*. Lambert academic publishing; 2013. ISBN-13: 978-365950177.
3. Wright C, Reeves P. RadBench: benchmarking image interpretation skills. *Radiography* 2016;**22**(2):131–6. https://doi.org/10.1016/j.radi.2015.12.010.
4. Loughran CF. Reporting of Fracture Radiographs by radiographers: the impact of a training programme. *Br J Radiol* 1994;**67**(802):945–50. https://doi.org/10.1259/0007-1285-67-802-945.
5. Neep MJ, Steffens T, Owen R, McPhail SM. A survey of radiographers' confidence and perceived accuracy in frontline image interpretation and continuing education preferences. *J Med Radiat Sci* 2014;**61**(2):69–77. https://doi.org/10.1002/jmrs.48.
6. Hardy M, Culpan G. Accident and emergency radiography: a comparison of radiographer commenting and "red dotting. *Radiography* 2007;**13**:65–71. https://doi.org/10.1016/j.radi.2005.09.009.
7. Hazell L, Motto J, Chipeya L. The Influence of Image Interpretation training on the accuracy of abnormality detection and written comments on musculoskeletal radiographs by South African Radiographers. *J Med Imaging Radiat Sci* 2015;**46**:302–8. https://doi.org/10.1016/j.jmir.2015.03.002.
8. Brealey S, Scally A, Hahn S, Thomas N, Godfrey C, Crane S, et al. Accuracy of radiographers red dot or triage of accident and emergency radiographs in clinical practice: a systematic review. *Clin Radiol* 2006;**61**(7):604–15. https://doi.org/10.1016/j.crad.2006.01.015.
9. Smith TN, Traise P, Cook A. The influence of a continuing education program on the image interpretation accuracy of rural radiographers. *Rural Rem Health* 2009;**9**(2):1145. Available from: http://www.rrh.org.au/articles/subviewnew.asp?ArticleID=1145.
10. Coleman L, Piper K. Radiographic interpretation of the appendicular skeleton: a comparison between casualty officers, nurse practitioners and radiographers. *Radiography* 2009;**15**(3):196–202. https://doi.org/10.1016/j.radi.2007.12.001.
11. Lancaster A, Hardy M. An investigation into the opportunities and barriers to participation in a radiographer comment scheme, in a multi-centre NHS trust. *Radiography* 2012;**18**(2):105–8. https://doi.org/10.1016/j.radi.2011.08.003.
12. Piper KJ, Paterson A. Initial image interpretation of appendicular skeletal radiographs: a comparison between nurses and radiographers. *Radiography* 2009;**15**(1):40–8. https://doi.org/10.1016/j.radi.2007.10.006.
13. Hargreaves J, Makay S. The accuracy of the red dot system: can it improve with training? *Radiography* 2003;**9**:283–9. https://doi.org/10.1016/j.radi.2003.09.002.
14. Atta-Boateng M. *A survey to assess the willingness of Ghanaian radiographers to accept role extension as reporting radiographers*. Unpublished MSc. thesis. 2015.
15. Snaith B, Hardy M. The perceived impact of an emergency department in immediate reporting service: an exploratory survey. *Radiography* 2013;**19**(1):92–6. https://doi.org/10.1016/j.radi.2013.01.008.
16. Snaith BA. Radiographer-led discharge in accident and emergency- the results of a pilot project. *Radiography* 2007;**13**(1):13–7. https://doi.org/10.1016/j.radi.2005.11.002.
17. Williamson GR, Bellman L, Webster J. *Action research in nursing and healthcare*. London: Sage; 2012 Jan. https://doi.org/10.4135/9781446289112.
18. Winter R, Munn-Giddings C. *A handbook for action research in health and social care*. Kindle edition. London: Routledge; 2013.
19. Alexander K. Reducing error in radiographic interpretation. *Can Vet J* 2010;**51**(5):533–6. Available from:https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2857438/.
20. Berlin L. Risk management and malpractice defence: pitfalls of the vague radiology report. *Radiology Today* 2009;**10**(19):10. Available from: http://www.radiologytoday.net/archive/rt113009p10.shtml.
21. The Royal College of Radiologists. *Clinical radiology workload: guidance on radiologists' reporting figures*. London: The Royal College of Radiologists; 2012.
22. Yochum RT, Rowe L. *Essentials of skeletal radiology*. 3rd ed., vol. 1. Philadelphia, USA: Lippincott Williams & Wilkins publishing; 2004, ISBN 978-0781739467.
23. Ofori-Manteaw BB, Antwi WK, Arthur L. Ergonomics and occupational health issues in diagnostic imaging: a survey of the situation at the korle-bu teaching hospital. *J Health Med Nurs* 2015;**19**:93–101. Available from: http://www.iiste.org/Journals/index.php/JHMN/article/view/26759.
24. Goyal N, Jain N, Rachapalli V. Ergonomics in radiology. *Clin Radiol* 2009;**64**:119–26. https://doi.org/10.1016/j.crad.2008.08.003.
25. Piper K, Paterson A, Godfrey R. Accuracy of radiographers' reports in the interpretation of radiographic examinations of the skeletal system: a review of 6796 cases. *Radiography* 2005;**11**:27–34. https://doi.org/10.1016/j.radi.2004.05.004.
26. Somekh B, Lewin C. *Research methods in the social sciences*. London: Sage; 2005.
27. Smith T, Younger C. Accident and emergency radiological interpretation using the radiographer opinion form (ROF). *Radiographer* 2002;**49**(1):27–31.
28. Salajegheh A, Jahangiri A, Dolan-Evans E, Pakneshan S. A combination of traditional learning and e-learning can be more effective on radiological interpretation skills in medical students: a pre- and post-intervention study. *BMC Med Educ* 2016;**16**(1). https://doi.org/10.1186/s12909-016-0569-5.
29. Dmytriw A, Mok P, Gorelik N, Kavanaugh J, Brown P. Radiology in the undergraduate medical curriculum: too little, too late? *Med Sci Educ* 2015;**25**(3):223–7. https://doi.org/10.1007/s40670-015-0130-x.
30. Limchareon S, Kongprompsuk S. The value of medical student radiology education: a comparison of 1-week, 2-week, electives, and compulsories. *J Chin Med Assoc* 2018;**81**(6):548–51. https://doi.org/10.1016/j.jcma.2017.09.010.
31. Gunderman RB, Siddiqui AR, Heitkamp DE, Kipfer HD. The vital role of radiology in the medical school curriculum. *Am J Roentgenol* 2003;**180**(5):1239–42. https://doi.org/10.2214/ajr.180.5.1801239.
32. Seong HP, Jin MG, Chan-Hee J. Receiver operating characteristic (ROC) curve: practical review for radiologists. *Korean J Radiol* 2004;**5**(1):11–8. https://doi.org/10.3348/kjr.2004.5.1.11.