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Narrative Review

Orthopaedic surgeons' knowledge and practice of radiation safety when using fluoroscopy during procedures: A narrative review

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ABSTRACT

Objectives: The fluoroscopy environment poses a potential occupational radiation exposure risk to theatre personnel. Risks can be mitigated with effective application of radiation protection knowledge and methods. This review aimed to determine the link between orthopaedic surgeon's knowledge and the use of appropriate safety methods when using fluoroscopy.

Key Findings: A keyword search of three databases discovered six articles, totalling 2209 orthopaedic surgeons, who completed surveys to assess knowledge on various aspects of radiation safety and training. Participants had varying levels of experience. Moreover 1981 participants always wore a lead gown (89 %), while only 1052 participants wore thyroid protection (47 %). 449 participants (20 %) received some form of training.

Conclusion: Although surveys asked a range of questions it appeared that there was low knowledge of the ALARP principles. Usage of protective equipment is a legal requirement and thus was observed throughout, however, there were a number of incidences of disregarding some protective measures. Although there appeared to be limited knowledge surrounding radiation protection measures and lack of training provided, no clear link was demonstrated between compliance with protective methods and knowledge of the risks.

Implications for practice: Formal and continuous training should be provided for the enhancement of knowledge to ensure the safety of all staff and help prevent the long-term effects of ionising radiation when using fluoroscopy.

Introduction

Since the 1950's, fluoroscopy has become commonly used for orthopaedic procedures bringing many benefits: including improving surgical techniques, improving patient care, reducing morbidity rates, and shortening hospital stays.[1] C-arm fluoroscopy units provide X-ray images that allow surgeons to visualise real time progress of procedures and reduce surgery time by allowing surgical decisions to be made immediately.[2] In the fluoroscopy environment exposure to radiation can come from the primary beam, leakage and scattered X-ray beams.[3] However, of most concern to personnel are X-rays not absorbed by the patient diverted in other directions causing scattered radiation, thus resulting in secondary radiation exposure to the theatre staff[4] causing occupational exposure. The biological effects of radiation include deterministic effects, such as tissue reactions, hair loss and potential infertility,[5] however none of which have been recorded from the use of c-arm fluoroscopy.[1] Stochastic effects are proportional to long-term radiation dose received and could include catastrophic effects, such as malignancies and genetic mutations.[5] Research correlates personnel using fluoroscopy and increased diagnosis of malignancies, such as thyroid, gonad, and solid organ cancers.[1] Furthermore, incidence of breast cancer is increased among female orthopaedic surgeons compared to the general public.[6]

Internationally radiation protection legislations take into account recommendations of the International Commission on Radiological Protection (ICRP).[7] Basic standards of safety are recommended by the 2013/59/Euratom,[8] and national guidelines have been developed from this directive. There will be global variance in safety precautions and regulations, however the main principles of

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radiation protection are universal. In the UK the Ionising Radiations Regulations (IRR) 2017 rules that radiation doses received by staff members involved in ionising radiation procedures must never exceed 15 mSv per year or 1 mSv during pregnancy.[9] Furthermore, this regulation states that all staff must make use of personal protective equipment (PPE) supplied by the employer to prevent exposure from radiation.[9] The Ionising Radiation (Medical Exposure) Regulations (IR(ME)R) 2017 states that all personnel involved in ionising radiation procedures must have a vast range of knowledge surrounding the basic physics of radiation, the potential biological effects, be able to apply justification, and effectively dose optimise during the procedure to ensure the benefits outweigh all risks.[10] Furthermore, IR(ME)R (2017) places the obligations on specific duty holders and provides a framework to protect individuals from the hazards associated with medical and non-medical exposures involving ionising radiation. IR(ME)R identifies duty holders as: the 'employer': the persons responsible for health and safety matters who provide a framework within which duty holders should undertake their functions. It is their responsibility to ensure practitioners and operators are adequately trained (regulation 6). The 'referrer' who is required to supply the practitioner with sufficient medical information. 'Practitioner', is referred to in regulation 11(1) (b) as the person who evaluates the request information and considers the net benefit of the radiation exposure.[10] The 'operator', who is trained and entitled by the employer to undertake the practical aspects of a procedure. In the fluoroscopy environment it is possible for one individual to act as more than one duty holder, for example the orthopaedic surgeon can act as referrer, practitioner and operator.[11]

When the 'As Low as Reasonably Practicable' (ALARP) principle is applied, radiation doses received by the theatre staff can be minimised.[4] Achieving the ALARP principle means the benefits of obtaining the image must outweigh the risks; using lead rubber protection and increasing the distance from the radiation source are the most effective ways to reduce dose received by staff. Furthermore, communication between surgeon and radiographer should use effective terminology to prevent unnecessary radiation exposure.[4] Further guidance to personnel is in three guiding principles: time, distance and shielding. Time should be minimised with pulse fluoroscopy. Distance is a controllable variable following the inverse square law, where exposure reduces by a factor of ¼ with increasing distance by two.[12] Shielding is normally in the form of a lead rubber apron of lead equivalent 0.25 mm, whereas a lead equivalence of 0.35 mm has been proven to decrease exposure by 90 %.[13] Other forms of shielding are thyroid shields, caps and glasses, or ceiling mounted or tableside drapes.

A 2017 systematic review evaluating radiation exposure received by theatre staff during orthopaedic procedures, found that while dose received never exceeded the acceptable yearly threshold, it highlighted that the surgeon, and assistants closest to the radiation source, received the highest dose.[14] The review also revealed that surgeons' hands received the highest radiation doses, however lead rubber protection can significantly reduce the dose to areas covered. More experienced surgeons required less fluoroscopy images during procedures, therefore receiving lower radiation doses than their newer qualified counterparts. Educational interventions were suggested for the perceived lack of knowledge surrounding radiation safety; however, the systematic review did not fully assess surgeons' knowledge and awareness of how to protect themselves, other staff, and the patient.[14]

This review aims to evaluate current literature relating orthopaedic surgeons' knowledge and understanding of radiation safety, by answering the question 'are orthopaedic surgeons fully aware of the risks of ionising radiation when using fluoroscopy to assist them with procedures?' To assess effective methods of reducing radiation risks links between knowledge and mitigation compliance were sought, and questioned if orthopaedic surgeons received radiation safety training throughout their career. The review aimed to determine if recommendations may guide effective practice in future to ensure maximum safety against the potential risks of radiation.

Methods

Through procedural facilitation of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[15] a Boolean search (Table 1) was performed using MEDLINE, CINAHL and Scopus databases. Keyword search with MeSH, and citation analysis were conducted. Inclusion and exclusion criteria were applied (Table 1). Limitation was set to a five-year date range from 2017 to 2022 and the search performed in October 2022; limiting the search to a 5-year period, ensured research is relevant and considers current practices. Restrictions were set to peer-reviewed literature only, as this ensures that research included has undergone evaluation by other experts in the field resulting in the inclusion of only high-quality published research.[16] Articles that did not assess orthopaedic surgeons' knowledge, or assessed other factors such as radiation dose received, were excluded as they

Table 1
PEO framework used to identify key words for literature search, keywords used in literature search with inclusion and exclusion criteria.

PEO framework	Search strategy
Population	Orthopaedic Surgeons
Exposure	Radiation Safety
Outcome	Awareness and Knowledge of participants
Key words searched and Boolean operators used	"Orthopaedic Surgeon" OR "Orthopedic Surgeon" OR "Orthopedist" OR "Orthopedists"
	"knowledge" OR "awareness" OR "lack of awareness" OR "lack of understanding" OR "lack of knowledge"
	AND
	"radiation safety" OR "radiation risks" OR "radiation dose" OR "radiation exposure" OR "radiation"
Inclusion	Peer reviewed journal articles
	Quantitative research
	Articles between 2017 and 2022
	English language
	Articles that assess orthopaedic surgeons' awareness and/or knowledge towards radiation safety when using fluoroscopy
	Primary research only
Exclusion	Qualitative research
	Older than 5 years old
	Other specialities e.g. Urology
	Articles that focus on the radiation dose the surgeon/theatre staff receives during use of fluoroscopy
	Articles that do not assess knowledge or awareness of radiation safety

would not answer the research question. Review of qualitative research was initially considered, however, due to its absence in the pilot searches, the focus was survey based quantitative study designs. Resultant articles were appraised using the checklist 'critical appraisal of a cross sectional study'[17] which reviewed the strengths and limitations of each article. Specific information was extracted identifying commonalities and identifying important themes.

Results

The search identified 50 articles, a further article was noted during citation screening and excluded as it did not assess orthopaedic surgeons' knowledge of radiation safety. Title and abstract screening removed thirty unsuitable articles, after which full text of twenty articles were assessed for eligibility, and fourteen excluded for reasons such as not assessing surgeons' knowledge of radiation safety or non-participant research conducted, which would not answer the research question. Six studies[18,19,20,21,22,23] deemed eligible were included in this critical review (Fig. 1 & Table 2).

Quality appraisal

Two articles[19,20] conveyed greater strengths, as they clearly described participant selection methods, assessed statistical significance between variables, and had a satisfactory response rate. The remaining articles[18,21–23] contained more limitations, with two articles[21,22] scoring only partially or not at all in most criteria (Table 3).

Study design

All research distributed surveys, considered a common way to gather data in the health and social care sector.[24] Convenience sampling was used in all studies, considered a substandard method as results can be at risk of bias if all participants have similar backgrounds and can introduce uncontrolled factors affecting results; however, it ensures that participants will be suitable to the research.[25] This method also runs the risk of low response rates, for research to be reliable it is beneficial to have a greater than 40 % response rate.[26] The minimum response rate were exceeded by Tuncer[18] (91 %) and Ranade[20] (62.7 %), but Pires[19] (25.8 %) fell somewhat short of the reliability threshold. All other articles[21,22,23] did not provide numbers of distributed surveys, therefore their reliability in this regard cannot be assessed.

Two researchers[20,22] had expert input when creating surveys, adding validity, and ensuring questions were relevant.[26] Four researchers[18,19,22,23] published the survey, adding validity to the research, as doing so allows readers to identify factors measured, ensuring research is reliable and reproducible.[27] An advantageous method of distinguishing reliable results not due to chance is to assess statistical significance between variables,[28] however, two articles[21,22] failed to do this. No researchers discussed survey pilots, which could have added validity, as it ensures questions can be clearly answered and gives researchers a chance to address any issues prior to participants receiving it.[29]

All were subject to bias, such as selection bias, which occurs when some members of the population are more likely selected than others,[30] however, two researchers[21,23] reduced risk asking every member of the sampling frame to take part in the research. Response bias occurs when participants answer how they feel the researcher wants them to answer, normally a result of poor wording or when participants feel the need to conform to social norms.[30] All articles posed this risk, however, Tuncer[18] and Pires[19] reduced this including clear multiple-choice, rather than open ended questions or yes/no answers.

Thematic analysis

Themes emerging from the data extraction were: use of radiation protection, knowledge of ALARP and regulations, training received by participants, and statistical significance between variables.

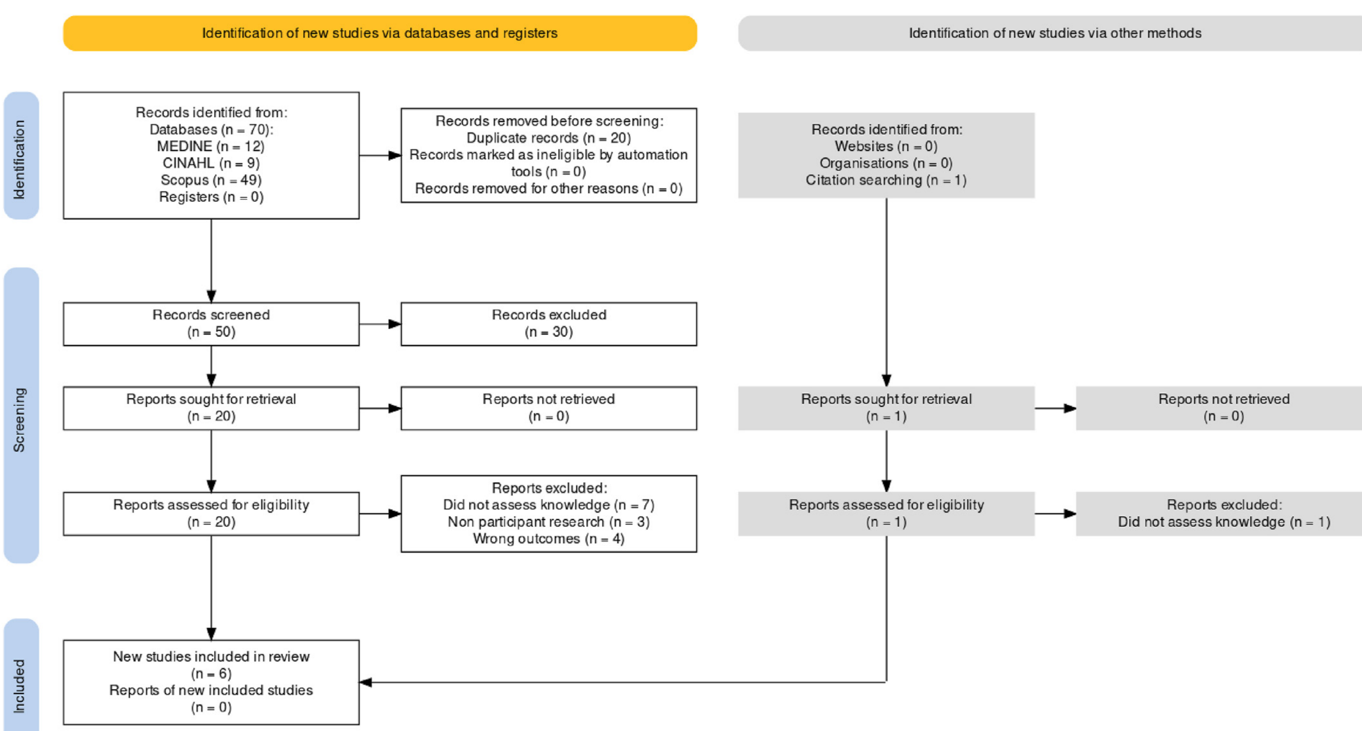

Figure 1. – PRISMA flow diagram – Adapted from Page et al.[12]

Table 2
Article characteristics.

First author and year	Place of Research and Relevant Legislation	Population sample and characteristics and response rate percentage	Radiation protection and equipment use	Knowledge of ALARP/ appropriate regulations	Formal or informal training provided	Any statistical significance reported
Tuncer et al. 2017[18]	Turkey -Regulation of Radiation Safety 2010[31]	Total n = 1024 Resident n = 513 Consultant n = 362 Professor n = 149 Response rate = 91 %	Lead rubber protection n = 870 Thyroid shield n = 716 Gonad protection n = 307 Lead glasses and gloves n = 51 Dosimeters n = 51	No discussion of ALARP/ regulations, Participants that were aware of radiation dose received n = 9	No discussion of training Read article on the use of fluoroscopy n = 87	Statistical significance was reported between levels of experience. No record of how this was performed
Pires et al. 2020[19]	Brazil – Basic guidelines for radiation protection 2014[32,33]	Total n = 258 Response rate = 25.8 %	Lead rubber protection n = 170 Lead rubber protection and thyroid shield n = 68 None n = 2 At least one form of protection used n = 256 Dosimeters n = 122	Knowledge of inverse square law n = 64 Knowledge of safe positioning of fluoroscopy unit n = 113 Knowledge of scatter radiation n = 141	Not assessed	Chi-squared test used to assess significant difference between speciality groups
Ranade et al. 2020[20]	India -Radiation Protection Rules 2004[34]	Total n = 439 Consultant n = 233 Trainee n = 206 Response rate = 62.7 %	Always use lead rubber protection n = 378 Sometimes/never use n = 61 Always use thyroid shield n = 43 Sometimes/never use thyroid shield n = 396 Dosimeter check n = 65	Aware of ALARP principles n = 71 Knowledge of inverse square law n = 200 Able to identify correct c-arm position n = 281 Knowledge of radiation doses n = 49 Knowledge of background radiation doses n = 51	Attended training n = 33 No training n = 406	Chi-squared test used to assess level of experience against variables and assessed significance of knowledge of ALARP against the use of protective equipment
Raza et al. 2021[21]	UK -Ionising Radiation Regulations 2017[4]	Total n = 406 Trainee n = 203 Consultant n = 111 Senior specialists n = 92 Response rate = unable to assess	Lead rubber protection n = 401 Thyroid shield n = 203 Lead glasses n = 60 Lead gloves n = 56 Dosimeters n = 109	Correct identification of annual radiation limits n = 219 Familiar with "employee duties" section of IRR or local rules n = 86 Knowledge of inverse square law n = 332	No training received at all n = 154 Training received (e-learning) n = 125 Training received (formal course) n = 127	None reported although identified as a limitation to the research
Sheth et al. 2022[22]	India -Radiation Protection Rules 2004[34]	Total n = 100 Resident n = 54 Consultant n = 46 Response rate = Unable to assess	Lead rubber protection n = 90 Thyroid shield n = 7 Lead glasses n = 0 Dosimeters n = 11	Knowledge of inverse square law n = 56 Knowledge of magnification risks n = 60 Knowledge of importance of collimation n = 18 Knowledge of benefits of pulsed fluoroscopy n = 22	Not assessed	None reported
Snowden et al. 2022[23]	Scotland -Ionising Radiation Regulations 2017[4]	Total n = 72 Consultants n = 28 Senior trainee n = 23 Junior Trainee n = 21 Response rate = unable to assess	Lead rubber protections n = 72 Thyroid shield n = 15 Dosimeter n = 2	Awareness of ALARP principle n = 27 Knowledge of scatter radiation n = 62 Awareness of methods to reduce scatter n = 56	Attended a course on radiation safety n = 40 Had in house training on radiation safety n = 37	Chi squared test used to examine significance between experience levels and training received

Use of radiation protection

All assessed the appropriate use of shielding for radiation protection while using fluoroscopy. Lead rubber apron protection were the most selected; Snowden[23] found all participants (72) used this. Pires[19] recorded the lowest number of lead rubber apron protection wearers 170 (65 %), although they did record that 256 participants (99 %) used at least one form of protection but the exact method was unclear. Lead rubber apron protection usage recorded in the other research was considered high, all citing compliance above 80 %. However, raises some concerns where lead rubber protection was not used (Table 2) as its use is a legal requirement in all surveyed countries: UK,[9] Turkey,[31] Brazil,[32,33] India.[34]

Table 3
Critical Appraisal of Cross-sectional Studies – Scores - 0 = not at all, 1 = partially, 2 = yes.

	Tuncer et al. 2017[18]	Pires et al. 2020[19]	Ranade et al. 2020[20]	Raza et al. 2021[21]	Sheth et al. 2022[22]	Snowden et al. 2022[23]
1. Did the study address a clearly focused question/issue?	2	2	2	2	2	2
2. Is the research method (study design) appropriate for answering the research question?	2	2	2	2	2	2
3. Is the method of selection of the subjects (employees, teams, divisions, organizations) clearly described?	1	2	2	2	1	2
4. Could the way the sample was obtained introduce (selection)bias?	1	1	1	1	1	1
5. Was the sample of subjects representative with regard to the population to which the findings will be referred?	2	2	2	2	2	2
6. Was the sample size based on pre-study considerations of statistical power?	0	0	0	0	0	0
7. Was a satisfactory response rate achieved?	2	1	2	1	1	1
8. Are the measurements (questionnaires) likely to be valid and reliable?	2	2	1	1	2	2
9. Was the statistical significance assessed?	2	2	2	0	0	2
10. Are confidence intervals given for the main results?	0	2	2	0	0	0
11. Have all confounding factors been accounted for?	0	0	0	0	0	0
12. Can the results be applied to your organization?	2	2	2	2	2	2
Total = /24	16/24	18/24	18/24	13/24	13/24	16/24

All found that thyroid protection use was low: Tuncer,[18] 716 (69 %), and Raza,[21] 203 (50 %). Sheth[22] reported only seven (7 %) participants used thyroid protection. Given that radiation induced thyroid cancer is a well-documented risk,[1,35] participants' knowledge of thyroid cancer could have been assessed to create a wider picture of why thyroid protection is not commonly used. All except Ranade,[20] asked participants if they wore a dosimeter, with a low rate of positive responses; Snowden[23] reported only two participants (2.7 %) used a dosimeter, while Pires[19] recorded the highest response 122 participants (47 %).

Knowledge of ALARP/regulations

Participant's awareness of the ALARP principle was measured by Snowden[23] who reported 27 (37.5 %), and Ranade[20] reporting 71 participants (16 %) having awareness. The other articles did not explicitly ask participant's awareness of the ALARP principle, this was alluded to by enquiring to knowledge of the inverse square law; 64 (24 %),[19] 200 (45.5 %),[20] 332 (81.7 %)[21] and 56 (56 %)[22] had such knowledge. Knowledge of the ALARP principle and methods of reducing radiation doses to theatre personnel can be implied with declared knowledge of the inverse square law. Snowden[23] asked if there was an understanding of how to reduce scattered radiation, 56 (77.8 %) agreed, however they did not identify specific methods, which would have enhanced the credibility of this results. Sheth[22] found that 60 (60 %) had knowledge of magnification risks, however only 18 (18 %) had knowledge surrounding the importance of collimation. Pires[19] and Ranade[20] assessed if participants knew how to correctly position the C-arm during procedures, with Pires[19] asking participants to demonstrate on a diagram of the C-arm. Pires[19] found that 113 participants (43 %), and Randade[20] 281 participants (64 %), answered that they knew how to position the C-arm correctly.

Training

Two articles[19,22] did not ask questions relating to training. Tuncer[18] asked if participants had read articles on radiation safety, where 87 (8.4 %) had done so, however did not ask any further questions relating to radiation safety training. Ranade[20] collected yes/no responses when asking if participants had ever received training, with 406 (92.4 %) citing no training received; no specific types of training were assessed. Conversely, others assessed types of training, Raza[21] deduced 125 (30.7 %) undertook e-learning, 127 (31.2 %) attended a training course, and 154 (38.1 %) received no training, and Snowden[23] found 37 (51.3 %) had in-house training and 40 (55.5 %) had no training.

There was minimal mention of the role of the radiographer throughout. Raza[21] recognised that it is both the surgeon's and the radiographer's responsibility to follow ALARP principles, and also alluded to the fact that radiographers undergo far greater training in radiation safety. Their results also mentioned that 19 % of participants agreed that formal training was required if they were the operator for instance when using a mini C-arm unit. In the study carried out in India it is alluded that surgeons are routinely the operator due to a shortage of radiology technicians.[22] Another study found only (225) 22 % of participants seek support from their radiology technicians,[18] and not addressing the experience of the technician was considered a limitation by Ranade.[20]

Statistical significance between variables

Four articles[18–20,23] assessed significance between variables, however, variables differed for each article (Table 4). Tuncer[18] and Snowden[23] both assessed significance between experience of orthopaedic surgeon and other variables: Tuncer[18] assessed against reading articles surrounding radiation safety and found that it was not significant; Snowden[23] assessed against the completion of a radiation safety course and found a statistical significance with more senior consultants attending such a course and reading or writing research into radiation exposures during orthopaedic procedures. Pires[19] assessed significance between orthopaedic speciality types and radiation protection use, which was not statistically significant, however found a significance between specialities and the use of two or more pieces of protective equipment. They also assessed between correct C-arm positioning and specialities, use of dosimeter, knowledge that obese patients increase the overall radiation dose, knowledge of who receives more radiation – the surgeon or assistant. Pires[19] found almost no significance between these variables and orthopaedic speciality. Ranade[20] assessed the significance between the knowledge of the ALARP principle and the level of experience and found that trainees had significantly more knowledge of this than consultants. Participants who had knowledge of the ALARP principle were more likely to wear a lead rubber protection. Significance was observed between the level of experience and the likelihood of regularly checking dosimeter levels with more experienced surgeons understanding the importance of this.

Discussion

The research suggests that orthopaedic surgeons require more training on radiation safety to adequately protect themselves and the rest of the surgery team against these risks, as overall

Table 4
Summary of variables assessed and results.

Variables assessed	Tuncer[18]	Pires[19]	Ranade[20]	Snowden[23]
Level of experience vs number of participants that read article on radiation safety	$p > 0.5$	–	–	–
Level of experience vs completion of a radiation safety awareness course	–	–	–	$p < 0.00001$
Orthopaedic specialty vs radiation protection use	–	$p = 0.28$	–	–
Orthopaedic specialty vs the use of 2 or more items of protective equipment	–	$p < 0.0009$	–	–
Orthopaedic specialty vs the knowledge of correct C-arm positioning	–	$p = 0.61$	–	–
Orthopaedic specialty vs use of dosimeter	–	$p = 0.28$	–	–
Orthopaedic specialty vs knowledge that radiation dose increases in obese patients	–	$p = 0.48$	–	–
Orthopaedic speciality vs the knowledge of who receives most radiation dose – surgeon or assistant	–	$p = 0.46$	–	–
Level of experience vs knowledge of ALARP principle	–	–	$p < 0.001$	–
Knowledge of ALARP principle vs use of protective equipment	–	–	$p < 0001$	–
Level of experience vs likelihood of regularly checking dosimeter levels	–	–	$P < 0.000$	–
Findings and statistical significance results	No significance discovered	No significance discovered	Statistical significance was discovered with trainees more likely to have knowledge of the ALARP principle, participants who had knowledge of the ALARP principle were more likely to use protective equipment, and more experienced surgeons regularly checked radiation levels on their personal dosimeter	Statistical significance was discovered with more senior surgeons more likely to have completed a radiation safety awareness course

awareness and knowledge of the risks of ionising radiation appears to be low. One of the best methods of radiation safety is the use of protective equipment, which may be underutilised, however, there is no clear link between compliance with protective methods and the limited knowledge of the risks. There was limited mention of the role of the radiographer or the operator and their role in radiation protection, perhaps suggesting that their knowledge is undervalued. The suggestion that communication between surgeon and radiographer should use effective terminology to prevent unnecessary radiation exposure[4] was not adequately addressed.

Training undertaken by orthopaedic surgeons appears to be on a voluntary basis, which contributes to low attendance numbers and can be attributed to global variance in safety precautions and regulations. The highest response to training emerged from UK participants[21,23] where formal training courses were provided. This is to be expected given that the IRR 2017[9] and IR(ME)R[10] highlights the legal requirements to ensure the safety of all exposed to radiation, and the duty holder 'employer' is required to ensure appropriate training for practitioners and operators. It is concerning that there is a difference between training recorded in each research, given all countries involved have standard regulations that outline the legal provision of radiation safety training.[9,31–34] Furthermore, results suggest approximately only half of UK participants[21,23] surveyed received formal training, which questions the enforcement of legal procedures involving protection of staff against ionising radiation risks.

Provision of training could enhance knowledge of radiation safety and ALARP principles, however, no research assessed the statistical significance between training and knowledge, which can be considered a limitation of all studies. Inference is best related to research involving UK based participants[21,23] as a greater percentage of participants received some form of training compared to those in other countries and identified enhanced areas of knowledge surrounding radiation safety. However, knowledge of ALARP is low throughout, which highlights the need for increased knowledge of these principles, which is advised through universal guidance from the International Society of Radiographers and Radiological Technologists (ISRRT),[36] and implemented in each country's legal radiation regulations.[9,32–34] The results regarding links to knowledge and use of lead rubber protections collectively suggests a limited knowledge of mitigating the risks of ionising radiation, although it is evident that there are limitations to the research performed.

While all the articles were homogenous in study design, there were some disparities in the questions asked and the variables assessed. The differences in the variables assessed made comparison difficult, and potentially affected the validity and reliability of the results of this review. Although a systematic approach was used that ensures the results are reproducible, this is limited as only one reviewer performed search, screening and quality appraisal. To avoid errors in translation, only articles published in English were included in this review, potentially excluding valuable research in other languages, possibly introducing publication bias.[37] Further barriers were presented when investigating legislations from countries where English is not the primary language. For example, Brazil's Legislation[32] published in Portuguese, although a comparative article[33] does exist in English; however, the accuracy of this as a direct translation cannot be assessed.

Implications for Practice

In the United States, it is compulsory for all members of the theatre team to complete a training course and examination relating to radiation safety before entering the theatre environment[38]; however, further research[39] found that students and newly qualified surgeons had the most knowledge. Therefore, it can be suggested that this training should be continuous throughout their career; with the provision of a formal and continuous training programme. For this to be achievable, all organisations must ensure that training is available for all theatre staff, appropriate radiation monitoring is provided, and the highest quality protective equipment is available.[40] Standards and guidelines[41] suggests that there should be a modality lead radiographer in radiation safety, and should consider who will ensure legislation is followed, liaise appropriately with members of staff, and have procedures in place should standards fall short during audits. When considering the UK, it is prudent to consider where responsibility of using radiation protection lies. The duty holder 'operator' is responsible for all aspects of carrying out the medical exposure, this person is entitled by the employer after appropriate training. This is not necessarily a radiographer, and studies did not record who was responsible for overseeing radiation safety and lead rubber protection use in the fluoroscopy environment. Training should incorporate a basic understanding of ionising radiation as well as mitigations such as time, distance and shielding. Duty holders must be aware of appropriate techniques, such as minimising magnification, using pulsed rather than continuous fluoroscopy, good positioning and collimation.[42] If employers and theatre personnel followed this approach, staff could more readily adhere to legislations and maintain a high level of knowledge regarding radiation safety in an ever-developing profession.

Future research recommendations

Further exploration of findings of this review could provide more definitive reasons for actions or behaviours occurring, which would increase the validity of results.[43] For example, answers conveying non-adherence to lead rubber protection wearing can elicit further responses of alternative methods of radiation protection being used, such as lead equivalent screen or applying distance. Qualitative or mixed-methods research would allow participants to give more detailed answers to questions. A qualitative phenomenology[44] approach would allow participants to explain why they do or do not wear protective equipment, which would assess surgeons' attitudes and further knowledge towards radiation safety. This approach would also ensure participants can elaborate on any training received and learning outcomes achieved. Further research could include the role of the radiographer with a particular focus on the educational role they could provide in the theatre environment.

Conclusion

Research suggests orthopaedic surgeons' use of protective equipment against ionising radiation is generally not at the level required. Likewise, knowledge of safety procedures and principles for reducing exposure to ionising radiation while using fluoroscopy is far from adequate, although this review cannot determine a direct link between knowledge and non-compliance in using protective equipment. Furthermore, training designed to enhance knowledge of such safety principles is also underutilised, therefore formal and continuous training is recommended for the ongoing development and enhancement of knowledge and methods used to ensure radiation safety for all when using fluoroscopy to perform orthopaedic procedures. There is a much needed gap in the literature for qualitative research, addressing this may provide further answers in optimising radiation safety.

Conflict of interest statement

None.

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