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FULL PAPER

Radiation in orthopaedics (RIO) study: a national survey of UK orthopaedic surgeons

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Objectives: Orthopaedic surgeons have a responsibility to minimise risks of ionising radiation to patients, themselves and staff. This study aims to establish the understanding of radiation practice, legislation and risk by orthopaedic surgeons.
Methods: A nationwide online survey of UK-based orthopaedic surgeons was conducted. Participants answered 18 multiple-choice questions assessing level of radiation safety training, basic principles/knowledge of ionising radiation, relevant legislation and operating practice.
Results: A total of 406 surgeons completed the survey. 92% reported using intraoperative ionising radiation at least once per week. 38% received no formal training on radiation safety. Knowledge of basic principles of radiation and legislation was limited. There was variable knowledge when labelling an image intensifier machine and choosing its safest orientation. Poor uptake of radiation protection equipment was noted. Only 19% agreed they had adequate training in ionising radiation safety and 27% reported receiving adequate training in equipment emitting ionising radiation in the operating theatre.
Conclusion: Many orthopaedic surgeons in the UK do not believe they are adequately trained in radiation safety. There is a deficiency amongst practicing surgeons in basic knowledge, relevant legislation and practicalities of the use of ionising radiation in the operating room. This could potentially put patients and health-care professionals at additional risk. We recommend that a standardised national training programme on the basic principles and safety of ionising radiation is implemented for all practicing orthopaedic surgeons.
Advances in knowledge: This paper is the first UK national survey amongst orthopaedic surgeons and is one of the largest reported internationally.

INTRODUCTION

The use of ionising radiation is an essential part of modern trauma and orthopaedic surgery. Intraoperative imaging assists orthopaedic surgeons conducting fracture fixation, osteotomies and implant placement. Ionising radiation has become more relevant with the advent of minimally invasive surgery, which can reduce the need for large incisions and result in faster rehabilitation.[1]

Ionising radiation is potentially harmful. This includes risks to the patient, as well as surgeons, nursing staff, radiographers and members of the anaesthetic team. Consequently, there is strict legislation and regulatory control for use of ionising radiation in medical settings. In the UK, this exists in the form of Ionising Radiation (Medical Exposure) Regulations (IR(ME)R) 2017 (amended in 2018) and Ionising Radiation Regulations 2017 (IRR 17).[2,3] Orthopaedic surgeons, in collaboration with radiographers, have a responsibility to keep exposure of ionising radiation "as low as reasonably achievable" (ALARA).[4]

Despite the frequency in which orthopaedic surgeons are involved with the use of ionising radiation, there is no mandatory requirement in the UK for surgeons to undergo formal radiation education or safety training. Radiographers on the other hand undergo intensive training. Given the orthopaedic surgeon is in charge of requesting the images as needed in theatre, are closest to the machines, and are ultimately responsible for the patient's safety, this may seem surprising. The aim on this study is to establish the understanding of radiation practice, legislation and risk by orthopaedic doctors who encounter ionising radiation during their day to day work.

METHODS AND MATERIALS

We designed an online (Google) survey consisting of 18 multiple-choice questions(Supplementary Material 1).

The survey sought to assess the level of radiation safety training and whether surgeons found this adequate, basic principles and knowledge of ionising radiation as well as awareness of relevant legislation applied to the operating theatre setting.

The survey was distributed to orthopaedic surgeons currently working in the UK. All British Orthopaedic Association and Orthopaedic Trauma Society members were contacted. The survey was also distributed to current trainees via Training Programme Directors and British Orthopaedic Trainees Association regional representatives. Participation was encouraged via an online social media campaign on Twitter. The survey was conducted between September 2020 and January 2021.

RESULTS

Demographics

The nationwide survey received a total of 406 responses. 50% were orthopaedic trainee registrars (ST3 to ST8) and 27.5% were orthopaedic consultants. The remainder consisted of orthopaedic associate specialists, senior fellows, trust-grade registrars, core surgical trainees and senior house officers (SHOs).

The majority of surgeons (56%) worked at Trauma Units (TU) with 37% working in Major Trauma Centres (MTC). Geographical analysis showed 84% of respondents were based in England, followed by 9% in Scotland and the remainder from Northern Ireland and Wales (4 and 3% respectively).

When asked how often they used intraoperative X-rays (*e.g.* image intensifier) during their average work, 90% stated "weekly" or "more than once per week" with 2% reporting "daily" use.

Training

When questioned on whether they had received formal training on ionising radiation safety, over one-third (38%) stated they had received no teaching or training at all. For those who had received training, the majority (31%) was from e-learning with the remainder being either on a professional course, lecture or when learning to use their Trust's mini C-arm.

57% of surgeons stated formal training was not required for them to work with intraoperative X-rays in their current Trust with a further 24% being "unsure". 19% stated it was a requirement, with many commenting on the specific requirement of training for the mini C-arm machine as no radiographer is present.

Ionising radiation legislation

89% correctly identified IR(ME)R as an abbreviation for Ionising Radiation (Medical Exposure) Regulations. Over three quarters (79%) were not familiar with the "Employee duties" outlined in IRR 2017 or their local department's radiation "Local rules". 83% did not know who their local Radiation Protection Supervisor (RPS) was.

Ionising radiation basic knowledge

54% of surgeons correctly identified the UK's recommended annual limit on "*effective dose*" of radiation for adult employees as being 20 millisieverts. 62% correctly defined "*stochastic effect*". 39% were able to correctly equate a single Chest X-ray as the equivalent of a "few days" of natural background radiation with 20% choosing either the "few minutes" or "few hours" options.

82% correctly applied knowledge of the inverse square law principle of ionising radiation in recognising that doubling your distance from the X-ray source would reduce your exposure by a factor of 4. 15% incorrectly thought it reduced exposure by a factor of 2.

We showed the respondents the following image (Figure 1) and asked them to correctly label different parts of a standard image intensifier machine. This was poorly answered, as the graph in Figure 2 shows, with notable confusion in identifying collimator, image intensifier and X-ray tube.

Respondents were also shown a photograph demonstrating two positions of an image intensifier machine (Figure 3) and asked which position would increase the amount of radiation scatter to the head/neck of the operating surgeon when performing a standard peripheral limb open reduction internal fixation (ORIF). There was a clear division of thought with only 55% correctly identifying image A and 44% choosing image B (Figure 4). The remaining 1% wrote free-text answers stating it depended on whether the surgeon was sitting or standing.

Radiation protection equipment

The prevalence of orthopaedic surgeons wearing lead-protective equipment when operating with intraoperative radiation was also analysed. The results of this are shown in Figure 5, with 99% of surgeons wearing lead aprons. 50% of respondents stated they used thyroid shields only sometimes, rarely or never. 85% never used lead protective glasses, 86% never used lead protective gloves and 77% never used radiation dosimeters or badges.

Opinion statements

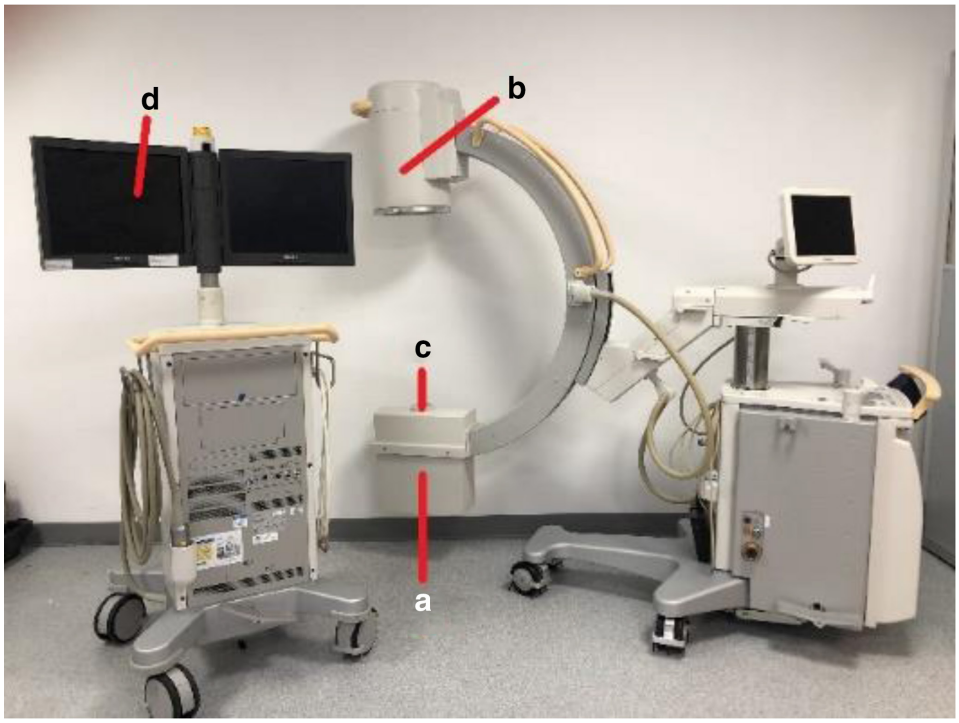
The final survey questions asked to what extent the respondent agreed with statements relating to training in ionising radiation safety knowledge and legislation; and training in use and principles of radiation equipment (*e.g.* image intensifier). Only 19% agreed or strongly agreed that they were adequately trained in ionising radiation safety knowledge and legislation (Figure 6). Only 27% agreed or strongly agreed that they were adequately trained in the principles of radiation equipment in the operating theatre (Figure 7).

Our final question asked whether respondents felt they were provided with adequate radiation protection equipment when operating. Less than a third (29%) agreed that they had sufficient provision (Figure 8).

DISCUSSION

This national survey has highlighted multiple deficiencies in which orthopaedic surgeons can improve on their knowledge of ionising radiation basic principles, relevant important legislation as well as practicalities of using ionising radiation in the operating room. This study is one of largest reported surveys undertaken to assess radiation safety knowledge and principles

Figure 1. Annotated diagram of image intensifier machine. (a: X-ray tube; b: Image Intensifier; c: Collimator; d: Display screen).



for orthopaedic surgeons. The findings are supported by other studies in the literature,[5–17] the majority of which were smaller local or regional surveys with less than 90 orthopaedic surgeon responses.[5–11] Overall, they showed limited radiation safety knowledge, lack of formalised training and poor usage of radiation protective equipment.[5–11]

In the largest similar survey to date, Tuncer et al[12] (2017) analysed responses of 1024 Turkish orthopaedic surgeons. Despite concluding that orthopaedic surgeons have inadequate knowledge about the uses and risks of fluoroscopy, only 1 of their 12 questions tested radiation knowledge by asking whether the respondent knew the dose of radiation in standard AP hip imaging, of which only 0.8% answered correctly. A main outcome of the survey was evaluating use of fluoroscopy use with an average figure of 54.5 shots per case. The survey did however highlight similar trends in limited use of radiation protective equipment with the majority (85%) using lead aprons, followed by thyroid protectors (70%) and poor rates of protective eyewear or glove use (5%).

Figure 2. Graph showing responses to question asking to label different parts of image intensifier machine.

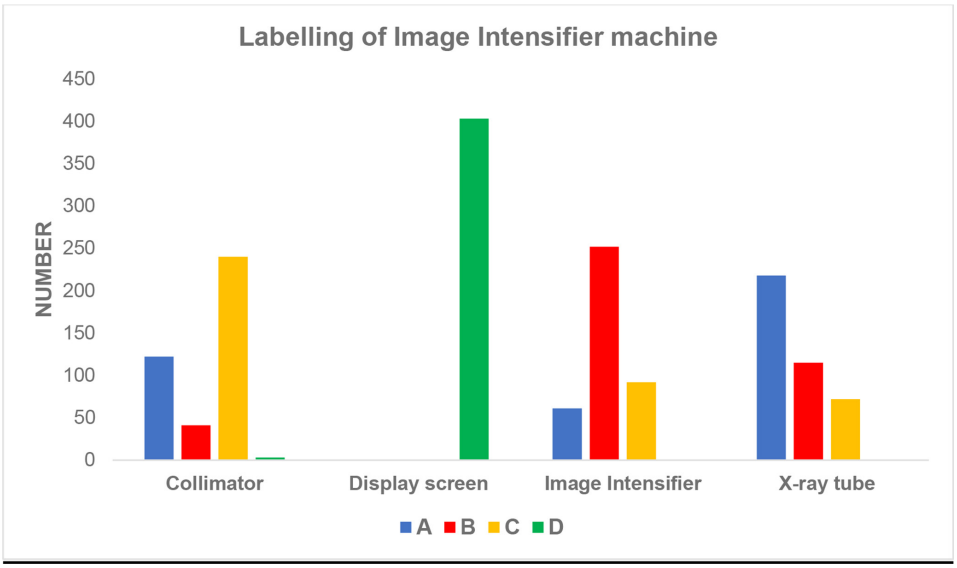
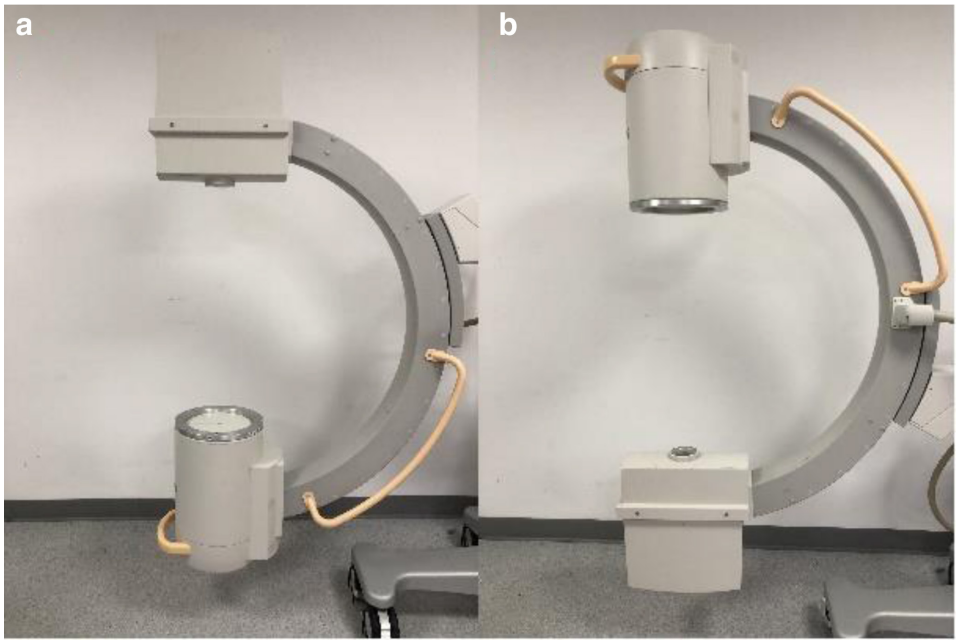


Figure 3. Diagram showing two positions of an image intensifier machine. (a: X-ray tube on top with image intensifier below; b: X-ray tube below with image intensifier above).



Similar national surveys have been undertaken which support our findings of lack of training and radiation safety knowledge amongst trainees and limited uptake of personal protective equipment. Bowman et al[16] analysed 517 responses from US orthopaedic residents and reported substantial knowledge gaps in occupational safety and limited use of personal protective equipment with lack of availability of such equipment leading to decreased compliance. Ranade et al[17] reported the findings of their national survey of Indian orthopaedic trainees and consultants. Their results from 439 respondents showed limited radiation safety knowledge with only 16.2% being aware of the ALARA principle. Interestingly, the authors reported a statistically significant increased uptake of personal protective equipment noted amongst those who were aware of the ALARA principle.

Falavigna et al[13] (2018) surveyed 371 spinal surgeons and reported low uptake of protective equipment and lack of knowledge in methods to reduce radiation exposure in the operating room. A national survey of 258 Brazilian orthopaedic surgeons also concluded there was inadequate theoretical and practical knowledge regarding radiation exposure with only a minority using basic radiation protection equipment.[14] Fidan et al[15] (2019) analysed 180 surgeon's responses and highlighted lack of radiation safety knowledge with only 12% having received training. Interestingly, only 68% wore lead aprons and 52%

Figure 4. Graph showing choices of image intensifier positions. (as seen in Figure 3; A: X-ray tube on top with image intensifier below; B: X-ray tube below with image intensifier above).

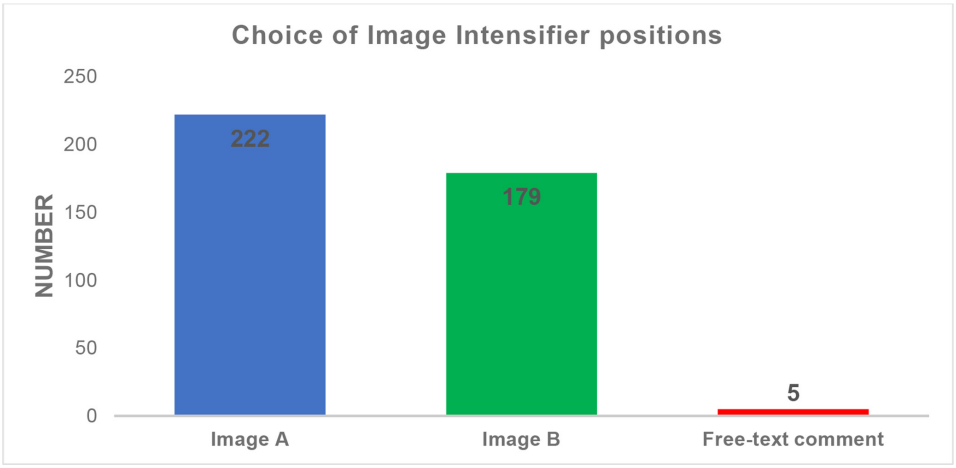
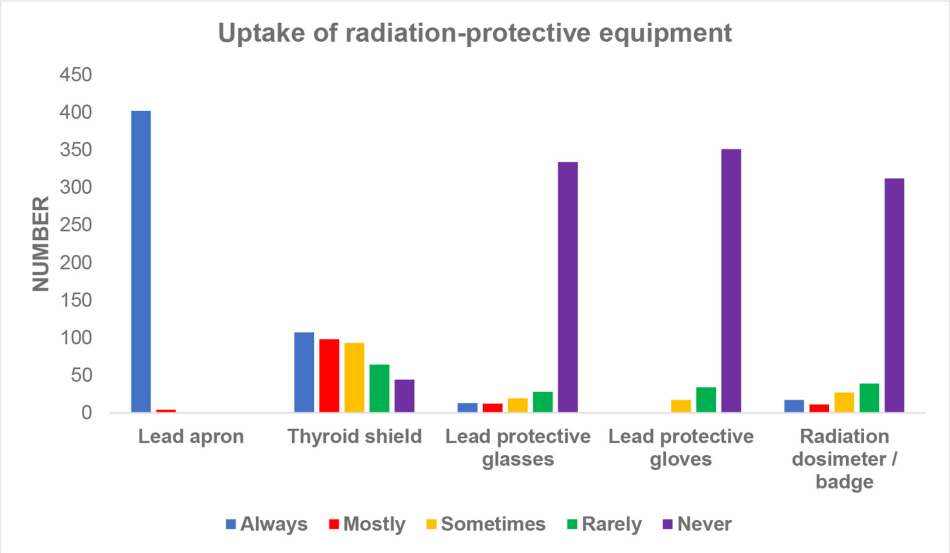


Figure 5. Graph showing uptake of radiation protection equipment



thyroid shields despite 87% of participants stating they were concerned about radiation exposure.

To our knowledge, this study is the largest European survey in terms of total responses and one of the largest reported internationally. However, we advocate it is the most comprehensive survey to date as it assesses multiple themes and provides objective data on current radiation safety training, basic radiation knowledge, relevant legislation and principles of ionising radiation in the operating theatre. Importantly, this survey differs from other comparable large surveys by providing both objective and subjective data by directly assessing the opinions of surgeons with respect to whether they feel they are adequately trained. In the context of no current mandatory training in radiation safety or basic principles for UK orthopaedic surgeons, this is of particular importance.

Demographic

With a survey response of 406 surgeons from four UK nations in both TU and MTC settings, we feel this survey is reflective of the UK orthopaedic community and the findings can be generalised. Importantly, 92% of surgeons stated they used intraoperative X-rays on either weekly, more than once weekly or daily basis. This highlights the importance of why orthopaedic surgeons need to be knowledgeable about ionising radiation safety, principles and practicalities.

Training

This survey showed poor evidence of formal training with 38% of surgeons receiving no training at all. In contrast, a US national survey reported 79.9% of orthopaedic residents receiving general safety training and 61.4% receiving operating room-specific

Figure 6. Graph showing extent of agreement with following: "I feel adequately trained in ionising radiation safety knowledge and legislation".

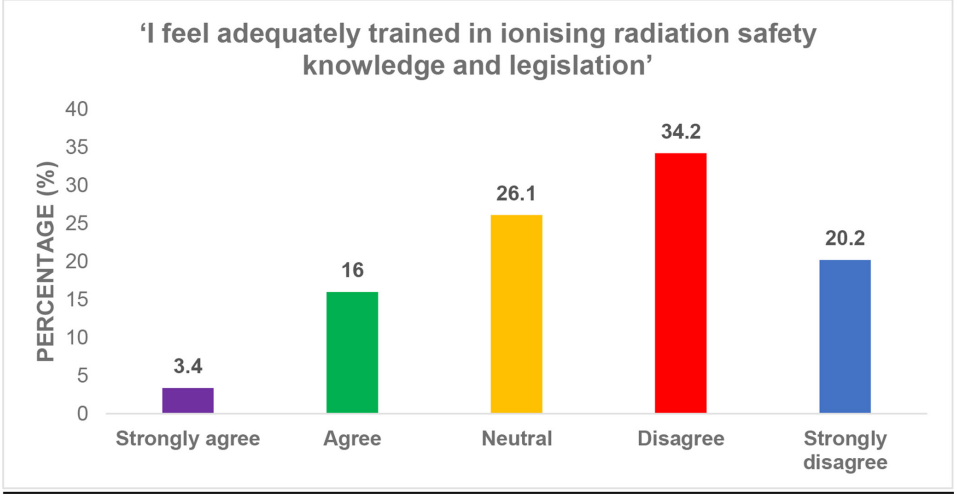
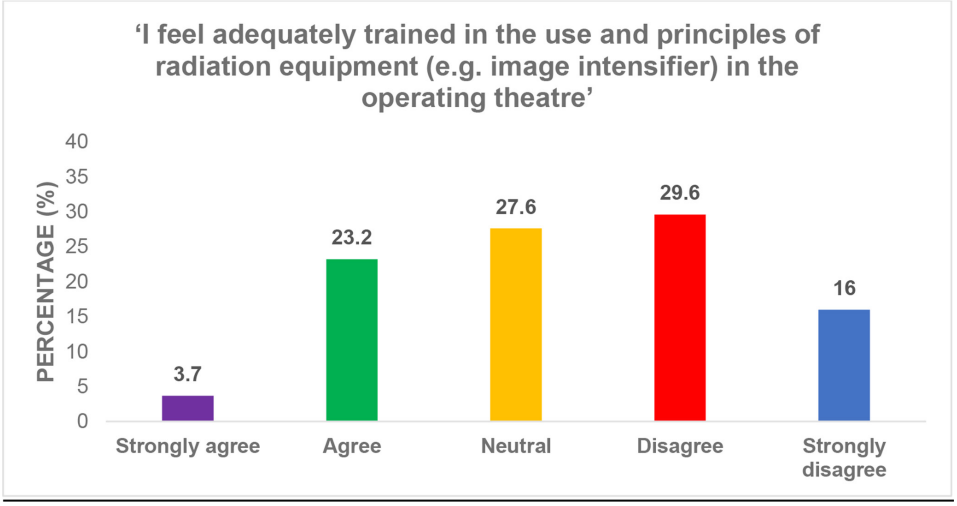


Figure 7. Graph showing extent of agreement with the following: "I feel adequately trained in the use and principles of radiation equipment (*e.g.* image intensifier) in the operating theatre".



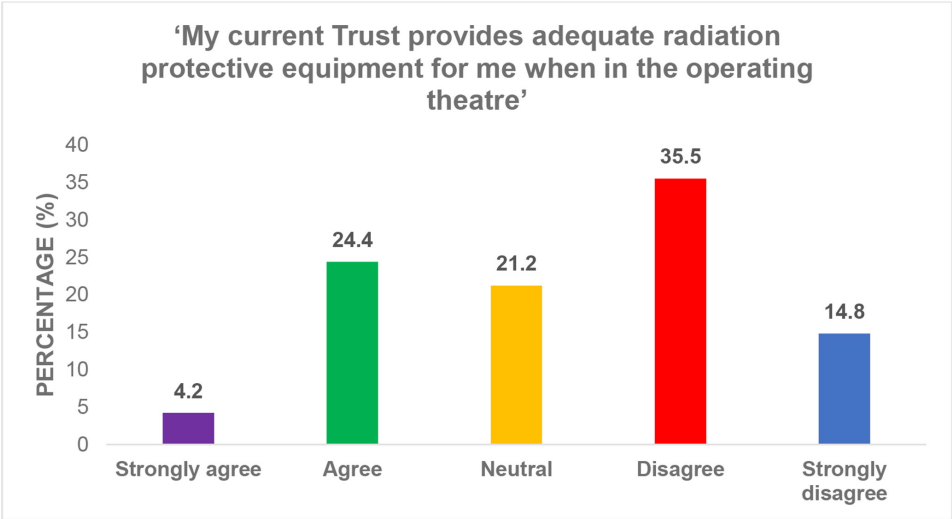
training.[16] In our responses, many commented that their only formal training was when required to independently use the mini C-arm machine at their hospital. Even with radiographers present and operating standard image intensifier machines, they are often guided by the operating surgeon as the image requestor. To this end, orthopaedic surgeons are required to have knowledge of these important safety principles. Over half (57%) stated there was no formal requirement for them to undergo training at their current Trust and a further 24% were unsure.

Despite the high frequency in which orthopaedic surgeons are directly involved with using ionising radiation, there is currently no mandatory requirement in the UK for surgeons to undergo formal radiation education or safety training. Health Education England (HEE), in collaboration with the Institute of Physics and Engineering in Medicine (IPEM), have created a free online e-IRMER course which allows users to gain certification after completing formal module assessments. However, this is currently an optional course for orthopaedic trainees with radiation training largely managed at a local hospital level. However, other UK speciality training programmes such as Cardiology require their trainees to attain formal certification in IRMER training.[18]

Studies looking at radiation safety training for orthopaedic surgeons using a mini C-arm have shown decreased radiation time and exposure to both patients and surgeons after implementation of a 3 hour training programme.[19] Training could provide increased knowledge for orthopaedic surgeons and potentially reduce unnecessary radiation exposure to patients and staff intraoperatively.

Unsurprisingly, this survey revealed a high dissatisfaction rate amongst orthopaedic surgeons with only 19% agreeing that their

Figure 8. Graph showing extent of agreement with the following: "My current Trust provides adequate radiation protective equipment for me when in the operating theatre".



training in radiation safety and legislation was adequate. This is lower than other international studies which have reported radiation safety training satisfaction rates for orthopaedic surgeons between 27 and 54%.[7,10] In addition, only 27% agreed their training in use and principles of radiation equipment was adequate.

These subjective findings show there is clear room for improvement in current training in radiation safety, legislation and use of specialist ionising radiation equipment. This, combined with the objective demonstration of deficiencies in knowledge of important radiation principles, is further evidence for the need for better training, ideally in the form of a standardised national training programme.

Ionising radiation basic principles knowledge

Knowledge of basic principles of ionising radiation is crucial for orthopaedic surgeons if we are to adhere to the ALARA principle for the safety of patients, ourselves and our colleagues. Unfortunately, this is clearly lacking in current UK practice.

Harmful effects of ionising radiation can be broadly categorised as either "stochastic" or "deterministic". The former is defined as effects occurring from cumulative exposure over a lifetime with no threshold dose required and potential increased risk of certain cancers and cataracts. In contrast, "deterministic" effects are threshold-dependent tissue reactions that can occur after high dose of radiation (*e.g.* skin/hair damage from cancer radiotherapy) and are unlikely in orthopaedic procedures due to significantly lower doses with intraoperative X-rays.[20]

Our survey showed that 38% were unable to choose the correct definition for "stochastic" effect and frequently confused it with "deterministic" effect or "compton" effect (where a photon interacts with an electron causing it to lose energy and change direction). The majority (82%) of surgeons were familiar with the "inverse square law" of doubling your distance from the X-ray source equating to a reduction in radiation dose by a factor of 4.

A key area of concern highlighted by the survey was regarding the safest position for the image intensifier when performing a standard peripheral limb ORIF. Only 55% correctly recognised that having the X-ray tube on top with the image intensifier below would increase radiation scatter to the head/neck of the operating surgeon (Figure 3). 44% chose Position B. 1% commented this would depend on whether the surgeon was sitting or standing. However, with the X-ray tube above the patient the surgeon will receive more scatter exposure regardless of sitting or standing. Standing with the tube on the bottom is the "safest" due to less scatter and maximum distance from the source. As scattered radiation is the main source of radiation for the surgical team, AO Trauma guidance is to have the X-ray tube below the patient as this reduces scatter exposure by up to 45%.[21] This set-up is also supported by other studies in the literature.[8,22–24]

This may have been affected by the confusion apparent when labelling the image intensifier machine. 46% of surgeons mislabelled the X-ray tube, 40% the collimator and 38% the image intensifier. Other studies have also shown surgeon's lack of knowledge in labelling or correctly positioning such equipment.[7,8,14] Despite its regular use in orthopaedic procedures, many surgeons are not familiar with basic components of the machine, perhaps relying on a radiographer to know how to use the machine correctly. Junior radiographers are frequently used in orthopaedic theatres with studies potentially showing higher overall radiation doses being administered by less experienced radiographers.[25] Consequently, it is important that orthopaedic surgeons are familiar with the machine and how to safely apply it to assist their operations without unnecessary ionising radiation exposure.

Radiation protection equipment

Use of radiation protection equipment was limited by our surgeons. Although lead aprons were worn by 99% of surgeons, 50% stated they used thyroid shields only sometimes, rarely or never. 85% never used lead protective glasses, 86% never used lead protective gloves and 77% never used radiation dosimeters or badges. These findings are supported by other studies showing poor uptake of protective equipment by orthopaedic surgeons.[5–10,12–17]

The importance of such equipment in minimising ionising radiation exposure is key due to well-documented carcinogenic risks of cumulative exposure. Surgeon's hands, eyes and thyroid are especially at risk due to their potential close proximity to the X-ray beam and increased radiosensitivity.[26,27] A recent systematic review reported reduced radiation exposure by 96.9 and 94.2% when wearing a thyroid collar and lead apron.[28] Wearing leaded glasses can also reduce radiation exposure by a factor of 10 and help prevent radiation-induced cataracts.[29] With an increasing prevalence of female orthopaedic surgeons, minimising radiation exposure especially when pregnant or lactating is also of increasing importance.[30,31]

A significant contributing factor to the poor uptake could be lack of availability. When asked about their local Trust providing adequate radiation protective equipment for their personal use, only 29% of surgeons felt they did. Under strict legislation as outlined by IRR 2017, all NHS trusts have a legal obligation to "take all necessary steps to restrict so far as is reasonably practicable the extent to which its employees and other persons are exposed to ionising radiation".[3]

Study limitations

A survey has limitations when attempting to generalise findings for the orthopaedic community. It is a snapshot survey to assess a cohort of UK based orthopaedic surgeons. The survey was not formally validated and statistical power analysis of data was not performed. Although we received 406 responses, this is still a small cohort of all current orthopaedic surgeons practicing in the UK.

However, we feel the survey has been carefully designed with the aid of a deputy superintendent radiographer. It has acted as a simple tool to assess a breadth of important topics that are relevant to everyday orthopaedic practice.

CONCLUSION

Ionising radiation is an important and widely utilised adjunct in orthopaedic theatres, although to be used safely surgeons should have a basic understanding of its principles. This study has highlighted objective findings of deficiencies in key areas of ionising radiation including basic knowledge, relevant legislation and practicalities of its use in the operating room amongst orthopaedic surgeons in the UK. Importantly, the survey has highlighted key subjective findings with only a minority of surgeons stating that their current training in use and principles of radiation equipment was adequate.

We recommend that a standardised national training programme on the basic principles and safety of ionising radiation is implemented for all practicing orthopaedic surgeons as part of the certificate for completion of training or revalidation.

As orthopaedic surgeons, we have a duty to act safely and minimise risks of ionising radiation according to the ALARA principle. With improved education and training, it is hoped this will improve the knowledge and everyday practice of current surgeons, benefiting the safety of our patients and colleagues.

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