Management of Patient Dose in Radiology: Which models can achieve optimisation?

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Abstract

There has been a steady expansion in the use of X-ray imaging during the last 10 years. Effective management of this increase requires robust arrangements for justification of exposures and optimisation of protection. Countries throughout the world are now undertaking surveys of patient dose, but these do not necessarily lead to optimisation of protection. A simple survey of organisational arrangements relating to X-ray equipment performance testing and management of patient dose has been undertaken. Over 120 completed survey forms were received from medical physics contacts in 40 countries. Some X-ray equipment performance testing was mandated in most countries (> 90%), with the tests being performed primarily by hospital or private medical physicists, although other groups are involved. Testing of equipment prior to clinical use was generally high for most regions, but there was considerable variation in frequency and regularity of subsequent testing. The prevalence of patient dose surveys was high in Europe, but lower in other regions. In order for dose surveys to have an impact, action must be taken upon the findings, but there may not be an effective link between surveyors and radiology facility staff to ensure that this is done. The survey provided insight into different approaches to organisation of testing X-ray equipment performance, patient dose surveys and optimisation of protection in medical exposures across the globe. Arrangements can be divided into four main groups. In Western Europe and Australia the process is led by hospital medical physicists with radiographer involvement. In the USA, Latin America and New Zealand private medical physicists test equipment and their involvement in optimisation is less clear. In Eastern Europe there is significant university involvement, but it is uncertain how wide the coverage might be, while in Africa and Asia government personnel and service engineers have a significant role in testing equipment.

Introduction

The application of X-ray imaging in medicine provides considerable benefit in diagnosis and management of disease. Nevertheless, all procedures using ionising radiation are thought to carry a small health risk. When the number of procedures that were performed was comparatively small, the overall risk to the health of the population could be disregarded. However, the numbers and range of procedures performed have risen and the complexity of the imaging techniques available has increased resulting in larger doses to more patients [Hall and Brenner 2008, NCRP 2009]. Perhaps most important of all, radiological imaging has begun to be used for more general screening of the population in some countries. Therefore, there is a greater need to optimise the applications of radiological techniques in order to achieve the correct balance between health benefit and harm. The approaches to the management of patient dose in different parts of the world are diverse. In some countries requirements may be enshrined in legislation that places obligations on those responsible for management of the radiology facility, as well as the clinicians and those carrying out the examinations [EU 1997, Martin 2011]. Enactment of such legislation will depend on the emphasis placed by government and the funding of institutions charged with enforcement. In other parts of the world, there may be no regulatory requirements and any measures taken to test equipment and optimise protection will be ad hoc, if they are undertaken at all.

There are several aspects to optimisation of protection and these include the performance testing of the X-ray equipment, the undertaking of surveys of patient dose and the use of the results in improving X-ray equipment settings and examination protocols. The various aspects may be carried out by different organisations or staff groups. The medical physics profession tend to form the group both most concerned about the optimisation of protection in medical exposures and having the scientific expertise to take the process forward. Therefore, in

order to gain an initial insight into variations in practice, a preliminary survey of medical physicists working in hospitals and other radiology facilities in countries throughout the world has been undertaken.

Materials and Methods

The survey involved collaboration between medical physicists working in different parts of the world. A questionnaire was prepared consisting of questions about the testing of X-ray equipment performance, the carrying out of patient dose surveys, and the use of data obtained in the optimisation of protection in medical exposures. The topics covered both the regulatory requirements and the arrangements in practice, and are listed in table 1. Lists of options were provided for questions about persons having responsibility and those carrying out the tests in order to simplify the subsequent data analysis. The original questionnaire was in English, but versions were translated into Portuguese (for Brazil) and Thai (for Thailand).

Table 1 Topics included in questionnaire

I.	**X-Ray equipment performance tests**
1.	National mandatory requirements to carry out X-Ray equipment performance tests. Requirement enforced through Regulations, Licence or Code of Practice.
2.	Standards against which equipment performance is measured.
3.	Person with responsibility for ensuring X-ray equipment tests are performed.
4.	Person carrying out X-Ray equipment performance tests.
5.	Types of X-Ray equipment tested before being used on patients.
6.	Types of X-Ray equipment tested routinely for compliance by a specialist.
7.	Types of X-Ray equipment tested routinely for constancy by users.
II.	**Patient dose surveys**
8.	National mandatory requirements for periodic patient dose surveys. Requirement enforced through Regulations, Licence or Code of Practice.
9.	Person with responsibility for ensuring periodic patient dose surveys are carried out.
10.	Person carrying out patient dose measurements.
11.	Types of X-Ray equipment for which dose surveys carried out.
III.	**Optimisation of protection in medical exposures**
12.	National mandatory requirements for the optimisation of protection for patients. Requirement enforced through Regulations, Licence or Code of Practice.
13.	Person with responsibility for ensuring optimisation is carried out.
14.	Person implementing optimisation of patient protection.
15.	Whether results from X-Ray equipment performance tests used in the optimisation.
16.	Whether results from the patient dose surveys used in the optimisation process
17.	Inspections or checks made by Regulatory Body to ensure that optimisation takes place.
18.	Types of examination for which national DRLs (diagnostic reference levels) available.
19.	Use made of national DRLs by facility as part of optimisation.
20.	Submission of patient dose survey results to body responsible for setting DRLs.
21.	Numbers of X-ray units in responder's facility.

Electronic versions were sent by email to medical physicists working in different parts of the world with whom the authors were in touch or had communicated with in the past, or individuals who had submitted papers on related topics to Radiation Protection journals within the last two years. Some medical physicists contacted were asked to pass on the questionnaire to colleagues in other centres, and this proved fruitful for obtaining additional data for Brazil, Scandinavia, the Philippines, and Thailand. Although it was recognized that to solicit voluntary participation could introduce a bias – only individuals who performed the tests would reply to the questionnaire– no attempt was made to screen or select particular groups of individuals, as this was intended to provide a snapshot of practices around the world for discussion. This resulted in certain countries having substantially larger data sets, while for others only a single questionnaire might be completed. However, the numbers of medical physicists actually practising in some countries is such that it would be difficult to find more than two or three medical physicists with the relevant knowledge practising in the country. The questionnaires were originally sent out in October 2011 and data collection was completed in February 2012. The questionnaires were completed predominantly by medical physicists who gave information about the practices in their radiology facilities or area. Thus, the survey is likely to provide a more optimistic picture for many countries in which provision of medical physics services is patchy. This is true particularly for parts of the world such as Latin America and Africa, where it might have been difficult for individuals already challenged by lack of resources and professional recognition, to acknowledge situations perceived by them as being below par. A slightly different approach was adopted for the United States of America (USA), since the regulations governing the use of X-rays are set at a State level and vary widely across the country. E-mail addresses for departments overseeing enforcement of state regulations were obtained from the Conference of Radiation Control Programme Directors (CRCPD) and questionnaires again sent by email. The respondents were in general from radiological protection sections of the state Departments of Health, responsible for overseeing regulatory compliance.

Table 2 Countries included in survey

Continent/Area	Countries/States
Africa	Algeria, Botswana, Gabon, Ghana, Mali, Niger, Sudan, Tanzania, Uganda, Zambia, Zimbabwe
Asia	Iran, Israel, Malaysia, Nepal, Philippines, Russia, Thailand,
Australasia	Australia, New Zealand
Eastern Europe	Bulgaria, Croatia, Greece, Macedonia, Serbia, Slovenia
Western Europe	Austria, France, Ireland, Norway, Portugal, Spain, Sweden, Switzerland, UK
Latin America	Argentina, Brazil, Colombia, Cuba, Mexico, Peru
USA	California, Colorado, Louisiana, Michigan, Nevada, New York, North Carolina, North Dakota, South Dakota, Vermont, Wisconsin, Washington State

About 200 questionnaires were sent out by E-mail to medical physicist colleagues around the world, but many more in Latin America were contacted through the "Radioprotección" and "FisicaMedica" Yahoo Groups networks of radiation protection specialists and medical physicists. A total of 123 replies from individuals working in 41 countries were received. There were a total of 110 separate pieces of information within each questionnaire and these were initially entered into an Excel spreadsheet and transferred to a Statistical Package for the Social Sciences (SPSS Statistics 17.0 for Windows) for analysis. The countries from which data were obtained are listed in table 2. Data relating to regulation, licensing, standards and responsibilities were analysed by country and for the USA by state. Where respondents gave different viewpoints, the majority viewpoint was used. The results are generally given by continent, plus a separate group for the USA. However, since Australasia contains only two countries which have different approaches to the provision of medical physics services, results for Australia and New Zealand are quoted separately in the text where this is appropriate. For questions relating to radiology facilities, data from all respondents are included. However, larger numbers of responses were obtained from Brazil and Thailand, for which the questionnaire had been translated into the local language. There were 24 responses from Brazil which made up 86% of the total from Latin America, and 13 from Thailand, which made up 62% of those from Asia. In order to avoid the response from one country dominating the results for these two continents, weighting factors were applied to the results so that no single country made up more than 40% of the total. A weighting factor of 0.125 was applied to

individual responses for Brazil, so that these made up 37% of the Latin America total, and results from Thailand were given a weighting of 0.25, so that they made up 29% of the Asian ones. For the remainder of the continents, apart from Australasia which only included Australia and New Zealand, no individual country made up more than 25% of the responses. Therefore the remaining responses were given an equal weighting.

Results

X-ray equipment performance tests

The initial questions related to mandatory requirements to carry out X-ray equipment performance tests. These results are summarised in figure 1. The majority of countries/states (76%) indicated that performance tests were required by regulations, and for 37% issue of a licence required tests to be performed. For only 7% was there no mandated need for performance tests. There were significant variations in requirements across the USA, with 67% of respondents indicating the requirement in regulations while for 33% it was simply in a code of practice. 21% of countries stated that there were no agreed guidance levels or standards available against which test results were compared. In 62% of countries the licensee or employer was identified as the person responsible for ensuring performance tests were carried out, although in 15% this was seen as being the head radiologist, and 12% the medical physicist. This may relate to the specialty of individuals employed in the facility or those seen as providing that aspect of the service.

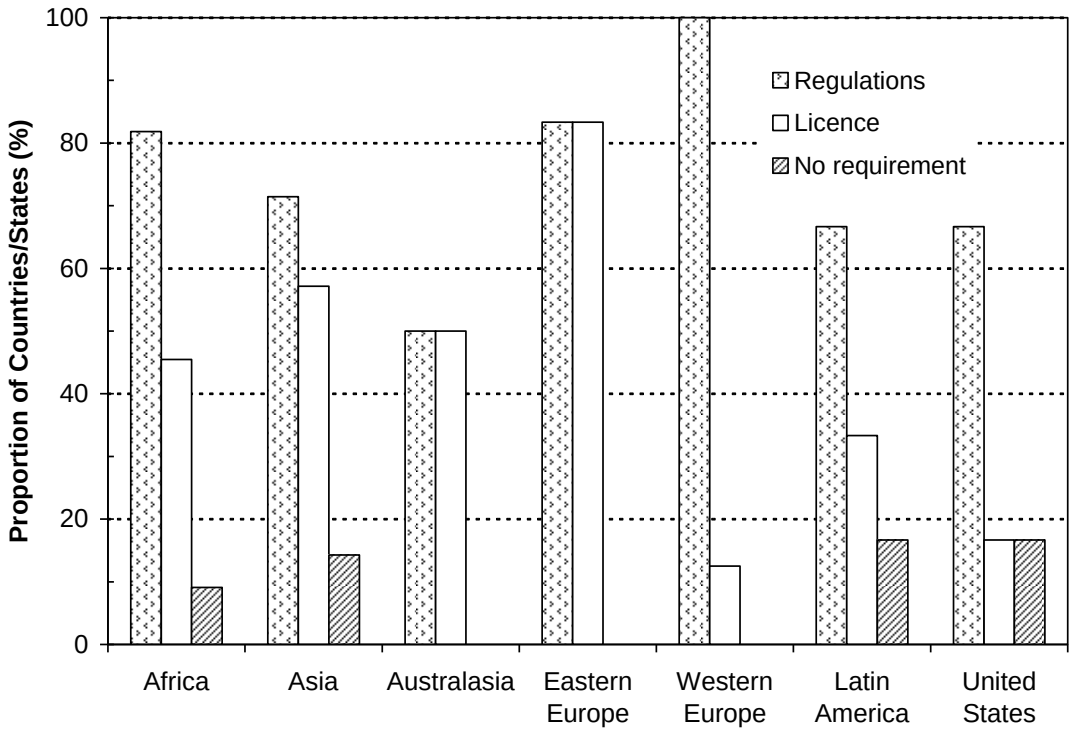

Figure 1 Proportion of responding countries in different continents requiring X-ray equipment performance tests through regulations and/or licence conditions or with no mandatory requirement. The last section relates to different states in the USA, which each have separate regulations.

The groups identified as carrying out performance tests on X-ray equipment are shown in figure 2. The numbers relate to the percentage of respondents, with the appropriate weighting applied. By and large it was medical physicists who took on the specialist role of carrying out performance tests on X-ray equipment, although the arrangements varied in different parts of the world. For instance in Western Europe and Australia, it was a medical physicist employed by the radiology facility who undertook these tests, whereas in the USA, New Zealand and Latin America, it was usually a medical physicist employed by an external private organisation who carried them out. The practice in Eastern Europe was split between these two groups, with university personnel perceived as having a significant role as well as the hospital medical physicist. In Asia and Africa practices are again varied with a number of different individuals identified as having this role.

Government personnel were indicated by 80% of respondents in Asia and 45% in Africa, but there was also a high prevalence of X-ray engineer involvement indicated by 45% of responses from Asia and 40% from Africa. Africa was the only continent for which some respondents (15%) indicated that no tests were performed.

Responses to questions about whether X-ray equipment was tested before it was put into clinical use indicated that in Europe, Africa, Asia and Australasia, this was done for 80%-100% of medical X-ray equipment and 70%-90% of dental X-ray units. However, in the United States only 50%-60% of respondents stated that performance tests were always carried out before X-ray equipment was used clinically, including only 50% for CT scanners. The remainder indicated that tests were performed sometimes. The one exception to this was for mammography equipment, where all units in the USA were tested. For Latin America only about 30% of respondents said that equipment was always tested before being used clinically.

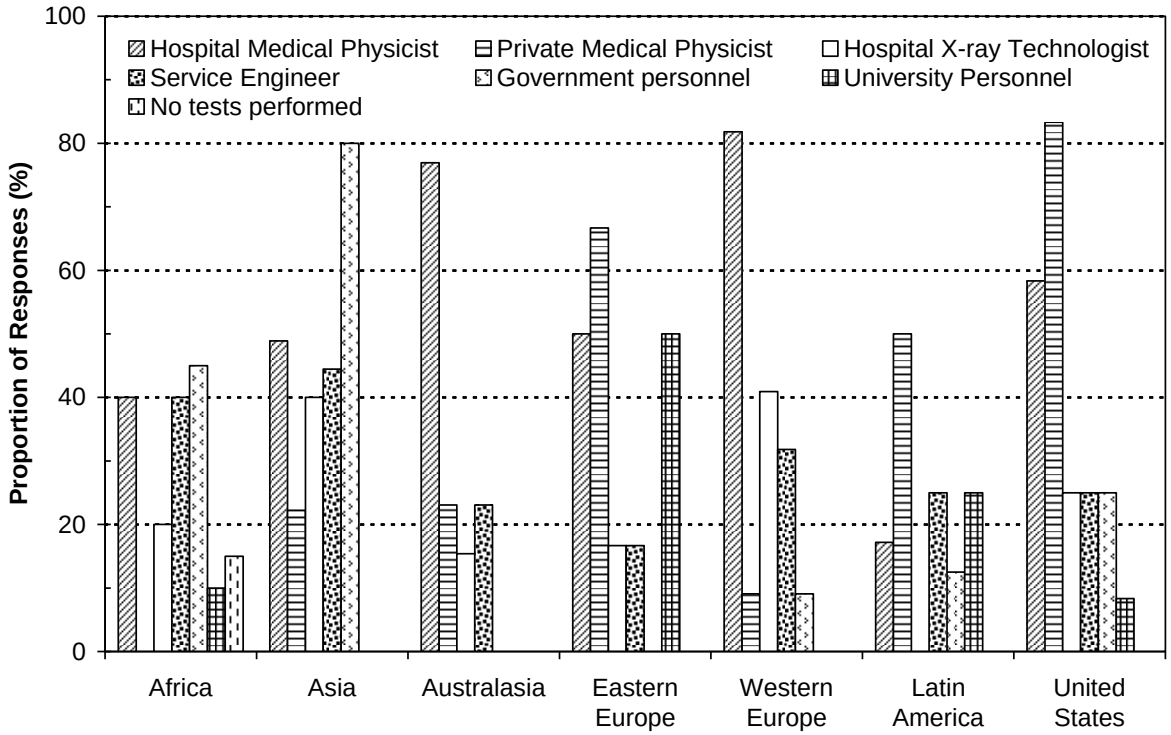

Figure 2 Personnel groups within each continent and the USA carrying out performance tests within radiology facilities of respondents to the questionnaire.

Information on the routine testing of medical X-ray equipment suggested that over 80% of medical X-ray units were tested in most continents, at least periodically. However, within Africa only between 30% and 50% of units were tested. The majority of tests were carried out annually, although about 20% of radiography and fluoroscopy equipment was tested at intervals of 2 years or more, and many respondents indicated that testing was only done on an ad hoc basis when required. Tests by a specialist medical physicist were supplemented with radiographer quality control tests. This appeared to be regular feature in Western Europe, Australasia, the USA and Latin America, but only occurred in about 40% of radiology facilities in Africa and Asia, and less than 20% in Eastern Europe. The responses describe the arrangements in radiology facilities where there is a medical physics involvement, but will not necessarily reflect the practice over whole countries.

Patient dose surveys

In order to determine the radiation doses that patients are actually receiving, it is necessary to gather information on settings used and make measurements of dose for actual patient examinations. Judgements can be made on dose levels, if there are standard values with which results can be compared and countries across the globe have been encouraged to set national diagnostic reference levels (DRLs) for this purpose. Responses were analysed by country in order to elucidate the proportion that had such DRLs in place. Bar charts showing

the overall distribution in the form of countries within each continent are shown in Figure 3. The vast majority of countries in Western Europe had DRLs for CT, radiography and fluoroscopy examinations, whereas the situation in the rest of the world was variable, for example, with New Zealand having DRLs, but not Australia; Brazil having DRLs, but not Colombia, Cuba, Mexico or Peru; and again the situation varying from State to State in the USA. The smallest proportion of countries having DRLs in place was in Africa with less than 10% for the countries from whom questionnaires were received having DRLs.

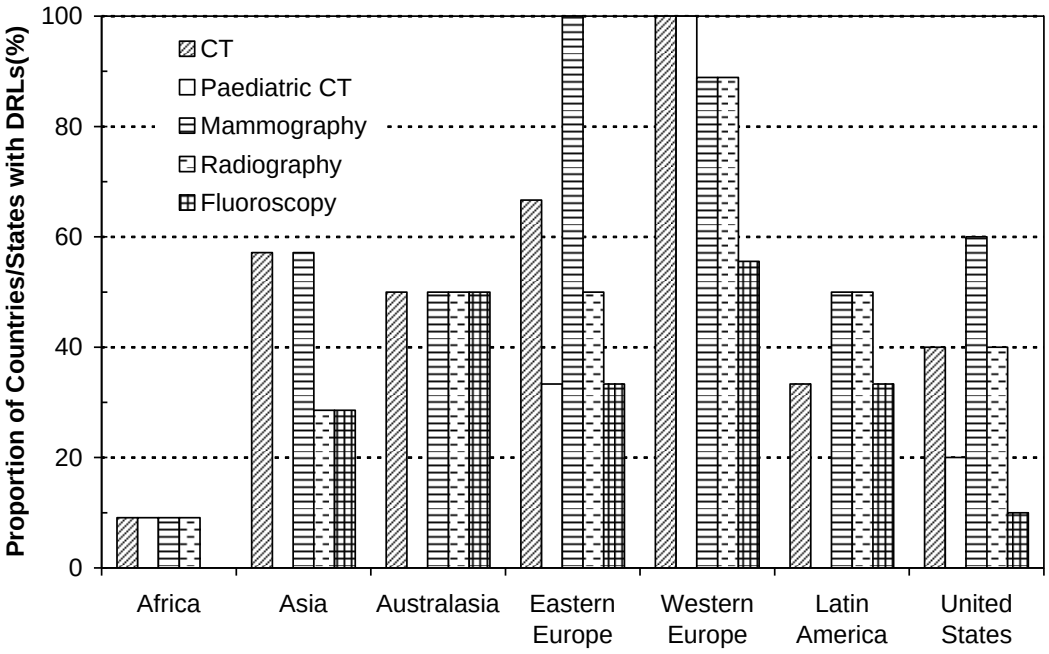

Figure 3 Proportion of countries and USA states with national/state DRLs for different types of examinations.

About 60% of the countries indicated that there were national requirements for patient dose surveys and the proportion carrying out surveys are shown in figure 4. Surveys of CT, mammography and radiography were performed most frequently with those for interventional and other fluoroscopy procedures being less frequent. Many responses indicated that the assessment of patient dose in mammography took the form of a measurement on a standard breast phantom, with actual patient dose surveys not being performed. In Europe surveys were performed for 50%-80% of each modality, but in Asia, Australasia, Latin America and the United States the proportions of surveys undertaken were generally less than 40%, and in Africa less than 10%. Results given by different radiology facilities within the same country varied.

Responsibility for ensuring that surveys of patient dose were carried out was considered to lie with the employer or licensee by 60% of respondents in Western Europe and New Zealand, 50% in the USA and 40% in Latin America. But substantial numbers of respondents in other parts of the world indicated that they considered that no-one had responsibility, amounting to 55% in Australia, 50% in Eastern Europe and 38% in Africa and Asia. About 30% of respondents in all these countries considered surveys to be the responsibility of the head medical physicist, and some in Africa (30%) and Asia (15%) also named the radiographer. This may indicate that these were the individuals who took on this task, rather than delegation of any mandatory responsibility. Dose surveys were in the majority of cases undertaken by medical physicists with 60%-80% of those in Europe and Australia being employed by the radiology facility and about 65% of those in the USA, Latin America and New Zealand being from private organisations (figure 5). In Eastern Europe, university personnel (67%) were identified as performing the dose surveys together with hospital medical physicists (50%). The situation was more variable in Africa and Asia, but hospital physicists were identified in 40% of responses as the group most likely to carry out the surveys if these were undertaken. Between 15% and 20% of patient dose surveys in both Africa and Asia were undertaken by university departments.

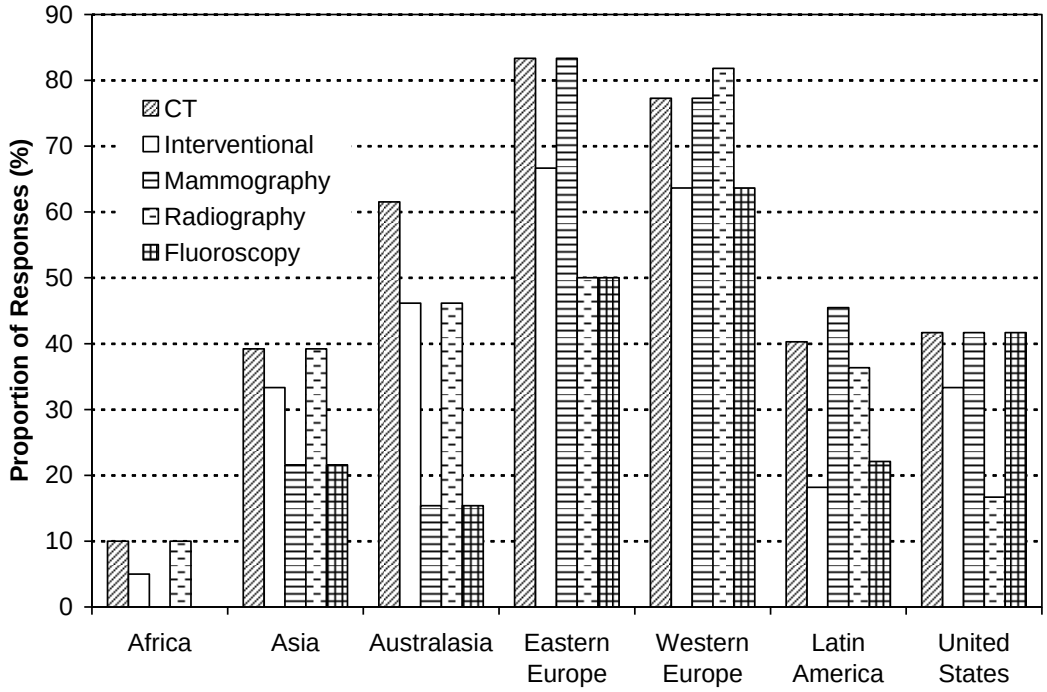

Figure 4 Proportion of responses in different continents and the USA indicating that surveys of patient dose for different types of examination were carried out in their radiology facilities.

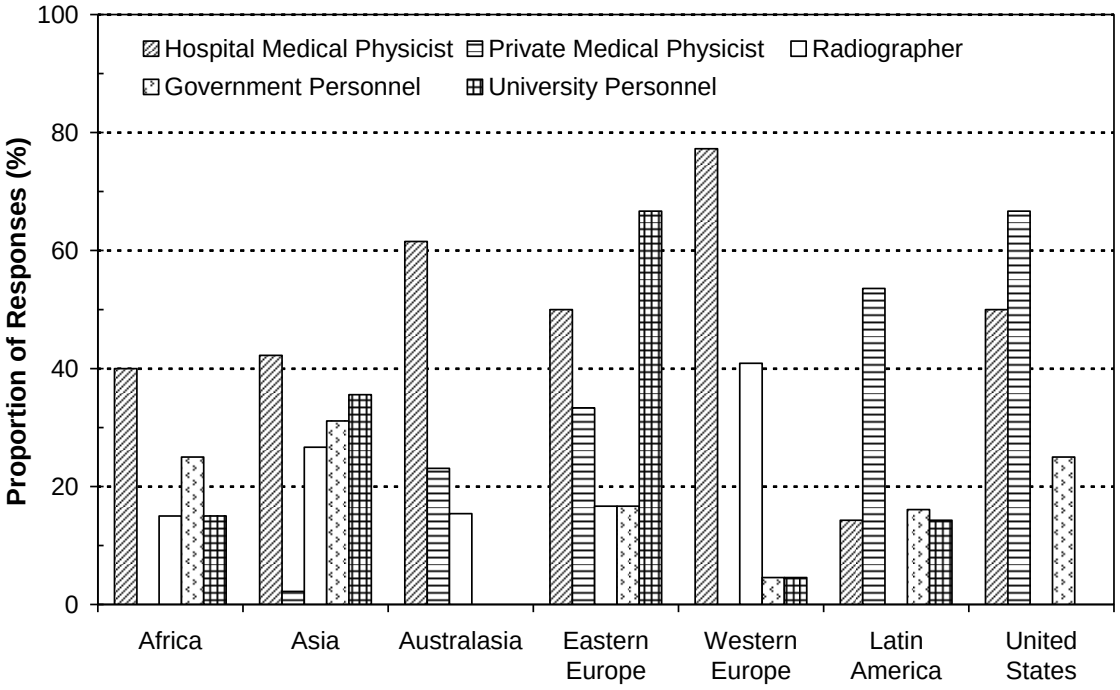

Figure 5 Personnel groups within each continent and the USA who carry out surveys of patient doses within radiology facilities of respondents to the questionnaire.

Optimisation of protection

In order to ensure that patient doses are kept to the minimum necessary to fulfil the clinical purpose it is important that consideration is given to optimisation of protection. Most of the respondents indicated that this was a mandatory requirement implemented through regulations, a licence or code of practice in their country, although there were some significant omissions. The licensee or employer was considered to have the main responsibility in 55% of cases in Western European and USA centres, and 30% of Australasian ones. But in about 30% of responses from the USA and Australasia, and 20% from Eastern Europe no-one was considered to have the responsibility. The head radiographer was identified as having responsibility in 50% of responses from Africa and 32% from Asia, and the medical physicist by 20% to 37% of respondents in most other groups.

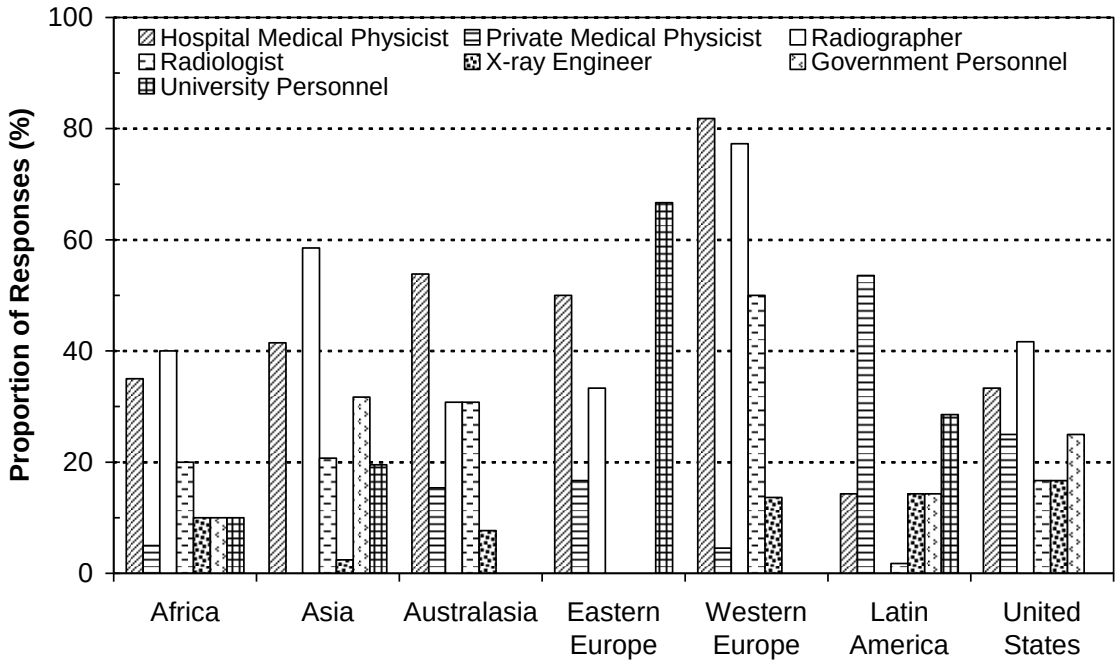

Figure 6 Personnel groups within each continent and the USA who carry out optimisation of protection within radiology facilities of respondents to the questionnaire.

The primary groups seen as having responsibility for carrying out optimisation were the radiographer in Africa (40%), Asia (58%) and the United States (42%), the hospital medical physicist in Australia (67%) and Western Europe (82%), private medical physicists in Latin America and New Zealand (50%), and university personnel in Eastern Europe (67%) (figure 6). 30% of respondents in Africa and Australasia, and 17% in the USA stated that no optimisation was performed. In Western Europe optimisation was seen as a collaborative process with involvement of the medical physicist, the radiographer (78%) and the radiologist (50%). While in Eastern Europe it involved university personnel, hospital medical physicists (50%) and radiographers (33%). The staff that implemented optimisation in Europe were thought to take into account results from both performance tests and patient dose surveys by 80%-100% of respondents. For Africa, Asia, Australasia and Latin America the link with both performance tests and patient dose surveys was seen to be more tenuous with only about 40% considering these were used. One factor in Africa could be a reliance on the X-ray engineer to carry out performance tests in many centres, and another is the smaller numbers of patient dose surveys undertaken. Results from the United States surveys suggested that the performance tests and patient dose survey results contributed little to the optimisation process. This may relate to the view of the group surveyed, or could reflect the fact that the surveys and performance tests are undertaken by medical physicists from private companies, who have a more restricted role in the optimisation process itself. There may be physicists working at individual radiology facilities who implement results, but the link between those carrying out

performance tests and patient dose surveys, and those involved in optimisation would not appear to be a strong one across all radiology facilities in the country as a whole.

Discussion

Consistent optimisation of protection for exposures in all radiology facilities requires an understanding of the factors that affect dose performance, confirmation that equipment is operating satisfactorily, and checks on image quality and patient dose in order to pick up units where inappropriate settings are being used or units are not operating correctly. Patterns of tests performed on X-ray equipment and those responsible varied throughout the world, but common elements could be identified. Responses to regulatory requirements suggest that there is a requirement for some checks on the performance of X-ray equipment in the majority of countries (figure 1). In the European Union, these are enshrined in legislation introduced under a European Directive and place obligations on those responsible for management of the radiology facility, as well as the clinicians and those carrying out the examinations [EU 1997, Martin 2011]. However, in other parts of the world, the regulation may be much less prescriptive if it exists at all and measures taken to test equipment and optimise protection in medical exposures are often ad hoc. Responses from between 10% and 20% of countries in Africa, Asia and Latin America, and some states in the USA indicated that there was no explicit requirement for such tests. Moreover, the question posed was in general terms, so the control may only apply to a restricted range of X-ray equipment. An example is the application to mammography in many USA states, where responses indicated that 100% of mammography units were tested before being put into clinical use — mammography being the only federally regulated medical imaging procedure— , while the proportions for other types of equipment were much lower, with only 50% of centres always testing CT scanners before clinical use. Respondents in Western Europe performed tests periodically on the majority of X-ray equipment (70%-90%), while for those in Australasia, Latin America and the United States the proportion was more variable (40%-90%). Routine performance tests were carried out on fewer units in Africa and Asia (30%-50%), and least in Eastern Europe.

In Europe a greater emphasis was placed on assessment of patient dose, with higher proportions of countries setting DRLs (figure 5) and a greater proportion of radiology facilities carrying out patient dose surveys (figure 6). Some radiology facilities in Asia, Australasia, Latin America and the USA carried out patient dose surveys, but there were few in Africa. These trends in different countries reflected those in setting DRLs.

The general approach to the management of patient dose is influenced by the individuals undertaking the performance tests and involved in the optimisation process. Within its limitations, results from the survey can be used to draw some general conclusions about the organisation of the management of patient dose in different parts of the world. The results from the different continents can be divided into four approaches: 1) Western Europe and Australia – hospital medical physics lead, 2) America, Latin America and New Zealand – private medical physics lead, 3) Eastern Europe – significant university involvement, and 4) Africa and Asia - varied with government personnel having a significant role as well as X-ray engineers. The legislation in Western Europe has resulted in a stronger hospital-based medical physics profession, and it is this staff group who carry out the majority of performance tests here. The hospital based physicists are also the ones carrying out the surveys of patient dose in Western Europe and Australia and are identified with the radiographers as having the greatest involvement in the optimisation process, with radiologists also contributing. The pattern in the USA, Latin America and New Zealand is for both performance tests and patient dose surveys when they are undertaken to be carried out by medical physicists from external organisations. In the USA the radiographer is seen as having the more important role, but in Latin America the private medical physicist is perceived as carrying the responsibility for optimisation. Since tests performed by this group tended to be on a more ad hoc basis it is unlikely the program of optimisation was rigorous. Communication between the medical physicist and the radiographer is likely to be crucial in ensuring optimisation is carried out effectively. In Eastern Europe, medical physicists from radiology facilities, private companies and universities all undertook performance tests on the equipment, and universities took the lead role in patient dose surveys, with the universities being perceived as taking a lead role in the optimisation process together with the radiology hospital physicists and the radiographer. The involvement of university personnel across the whole country is likely to be more limited, than a hospital based service, so the extent of the optimisation is difficult to judge, but respondents indicated that results from both performance tests and dose surveys were used in the optimisation process, where it was undertaken. The situation in Africa and Asia is more varied, which probably reflects the state of implementation. Here government personnel were the primary group undertaking

performance tests, although hospital medical physicists and X-ray engineers were also involved. Hospital medical physicists carried out patient dose surveys together with government personnel, and the radiographers were seen as the main group having responsibility for optimisation with some involvement from the hospital medical physicists.

Conclusion

Because of the nature of the distribution of the questionnaire, it is recognised that the results cannot purport to be truly representative of current practice with respect to equipment testing, patient dose surveys and the implementation of optimisation of protection worldwide. Nevertheless, the survey provides an insight into the different approaches to the organisation of testing X-ray equipment performance, carrying out patient dose surveys, and optimisation of protection in medical exposures across the globe.

Arrangements can be divided into four main groups. In Western Europe and Australia the process is lead by hospital medical physicists with radiographer involvement. Their involvement in optimisation is less clear in the USA, Eastern Europe and New Zealand, where private medical physicists were more likely to be the ones who tested equipment and, it would appear that a similar trend exists in Latin America, although the number of diagnostic medical physicists is very small. In Eastern Europe there is significant university involvement, but it is uncertain how wide the coverage might be, while in Africa and Asia government personnel and service engineers have a significant role in testing equipment.

For an optimisation strategy to be effective, those closely involved in the use of X-ray equipment need to have knowledge and access to results of performance testing and patient dose surveys. In addition there should be a continuing program of assessment to track any changes in equipment performance. The systems in Western Europe in particular provide close links between the different groups involved, namely the medical physicist based in the radiology facility and the radiographers, and so would appear to provide a greater opportunity for optimisation. The involvement of private medical physicists has the potential to provide the same link, but there is uncertainty about how well this works in practice. The expertise available in university departments can contribute useful scientific input, through the undertaking of patient dose surveys, but it is important that the researchers follow through and ensure that appropriate action is taken on any findings to ensure the optimisation process is completed.

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The authors aim to continue collection of data in order to gain a wider knowledge of the way patient dose is managed. Any reader willing to complete a questionnaire to allow data on their area to be added, survey should contact colin.martin@ggc.scot.nhs.uk.

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