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PAPER

A strategy for achieving optimisation of radiological protection in digital radiology proposed by ICRP

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Abstract

Radiology is now predominantly a digital medium and this has extended the flexibility, efficiency and application of medical imaging. Achieving the full benefit of digital radiology requires images to be of sufficient quality to make a reliable diagnosis for each patient, while minimising risks from radiation exposure, and so involves a careful balance between competing objectives. When an optimisation programme is undertaken, a knowledge of patient doses from surveys can be valuable in identifying areas needing attention. However, any dose reduction measures must not degrade image quality to the extent that it is inadequate for the clinical purpose. The move to digital imaging has enabled versatile image acquisition and presentation, including multi-modality display and quantitative assessment, with post-processing options that adjust for optimal viewing. This means that the appearance of an image is unlikely to give any indication when the dose is higher than necessary. Moreover, options to improve performance of imaging equipment add to its complexity, so operators require extensive training to be able to achieve this. Optimisation is a continuous rather than single stage process that requires regular monitoring, review, and analysis of performance feeding into improvement and development of imaging protocols. The ICRP is in the process of publishing two reports about optimisation in digital radiology. The first report sets out components needed to ensure that a radiology service can carry optimisation through. It describes how imaging professionals should work together as a team and explains the benefits of having appropriate methodologies to monitor performance, together with the knowledge and expertise required to use them effectively. It emphasises the need for development of organisational processes that ensure tasks are carried out. The second ICRP report deals with practical requirements for optimisation of different digital radiology modalities, and builds on information provided in earlier modality specific ICRP publications.

1. Introduction

The use of radiological imaging in medicine for diagnosis and guiding interventions continues to expand. The increased use of imaging in the management of individual patients means that the optimisation of radiological protection aspects becomes even more important. Radiation doses from medical applications make up a significant component of the radiation dose received by populations in Europe, America, and elsewhere [1–4]. The core principles of optimisation of radiological protection relating to clinical images are:

(1) the images should be of sufficient quality to ensure an accurate and reliable diagnosis, and enable correct clinical decisions to be made, and
(2) the radiation doses used to achieve the images should have been adjusted to the minimum level required to provide an adequate image.

Although the objective for optimisation of medical images is clear, it is not always obvious to staff involved what practical steps need to be taken and how an organisation should go about implementing them. There are many different components to optimisation requiring skills of a number of different imaging and radiological protection professionals. The radiologist or other medical radiological practitioner interpreting the images is the only one who can judge whether the quality is adequate to provide the clinical information required for management of the patient. The radiographer/imaging technologist has knowledge of the practical aspects of imaging equipment, techniques and exposure factors to perform the examination. The medical physicist understands the science behind image formation and radiation exposure and can assess the dose level and technical aspects of the imaging performance. The knowledge, skill and expertise of these professionals all feed into the process for optimisation of radiological protection. However, optimisation requires actions to be taken and is not going to happen without effort and support from all the professionals involved, management commitment to secure adequate resources are provided, and a structural framework to ensure tasks are carried out. In modern digital medical imaging, capabilities and tools for successful optimisation also relate to utilisation of radiological big data with appropriate analysis and monitoring systems.

Optimisation of radiological protection should be considered from the point at which any imaging facility is being planned. Factors to be considered include the amount of imaging equipment required to provide for the needs of the hospital and the number of adequately trained staff necessary for its proper use. Therefore, the optimisation process starts with specification of x-ray equipment requirements to fulfil the clinical need, followed by its purchase, installation, acceptance, and commissioning. Plans must be put in place for maintenance and a quality assurance (QA) programme at the outset and should continue throughout the life cycle of the equipment [5]. Once an imaging facility has been set up, identifying what is required and whether each hospital has everything in place to achieve optimisation is not straight forward, and varies with different facilities and the ways in which radiology departments are organised.

2. The ICRP approach to optimisation in digital radiology

The International Commission for Radiological Protection (ICRP) set up Task Group 108 in 2018 with the aim of preparing guidance on optimisation of radiological protection in digital radiology. Several different components that need to be developed within an organisation have been identified that contribute to successful implementation of optimisation of protection in radiology [6]. They each play a significant role either in ensuring the expertise that is available is fully utilised or that tasks required are performed. These are set out in a report prepared by the Task Group [7]. The first is collaboration between radiologists/clinicians, radiographers, and medical physicists (the 'core team'), each of whom have their own key skills. The different professionals will contribute to the process more effectively when individuals work together as a team and respect each other's unique expertise and distinct roles. The second is having appropriate methodologies and technologies to assess performance in relation to the clinical task, with the knowledge and experience required to use each effectively and interpret the results. The third relates to organisational processes that ensure required tasks, such as tests of equipment performance, patient dose surveys, and reviews of protocols are carried out regularly. Optimisation is not just an internal process. In order to ensure that best practice is followed, it is necessary to compare data and information on techniques used with other centres, so that performance can be assessed and evaluated. In order to achieve this, additional knowledge and expertise should be sought from attendance at professional educational meetings, conferences, and multidisciplinary events, as well as continual review of relevant literature. In this way the core team is able to continuously expand the expertise of the members through sharing the experiences of other centres and can incorporate new techniques into local imaging protocols where appropriate.

There is a wide range in equipment, funding, and imaging expertise around the world, and most facilities do not have all the tools, nor the professional expertise to fully embrace all the possibilities for optimisation of radiological protection. Therefore, broad levels of performance for the various aspects of optimisation that different facilities might achieve are set out in the report, through which each centre can potentially progress incrementally. These levels are described as D: Preliminary, C: Basic, B: Intermediate, and A: Advanced. Imaging facilities may consider the arrangements they already have in place and use the document to guide decisions about the next actions to be taken in optimising their imaging services to allow them to move up through the hierarchy D to A. The approach of separating out the different parts of the optimisation process

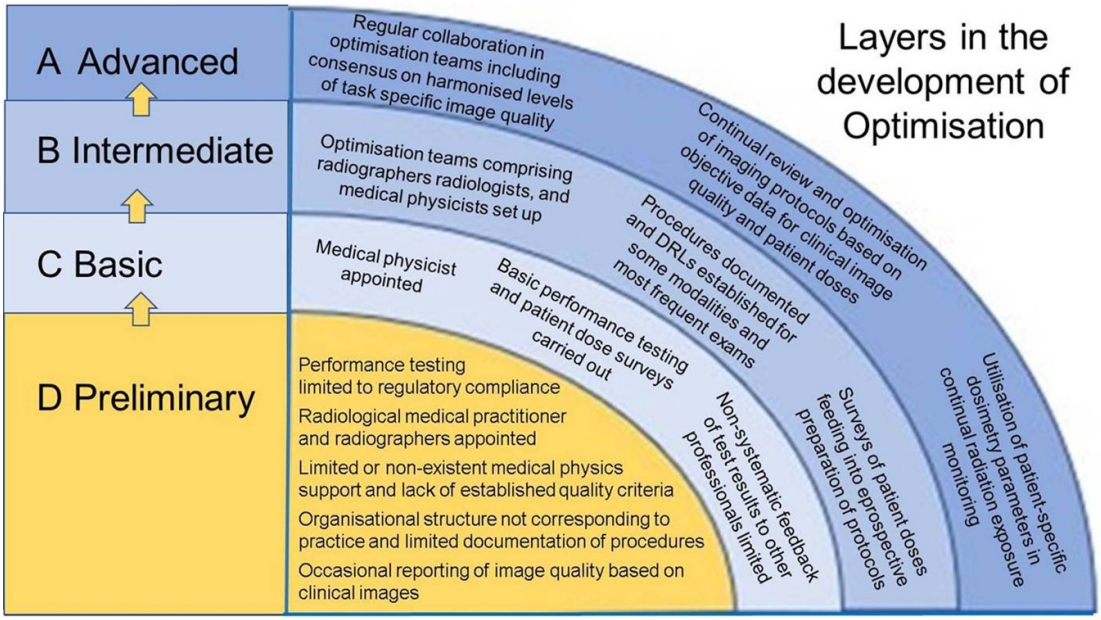

Figure 1. Illustration of layers linked to resources and activities that would be added during the implementation and development of optimisation within a radiology department. Figure reproduced with permission from ICRP [7].

and defining different levels of performance within each is considered to be appropriate for diagnostic radiology, because of the diversity in the types of facilities, expertise and funding that is involved. It can be considered as the addition of layers, in the form of expanding roles and additional tasks, to the overall service as a process of continual improvement (figure 1).

2.1. Professionalism—the multi-disciplinary team

The professional groups involved most directly in optimisation are radiologists, radiographers and medical physicists. Optimisation teams comprising members from the three professions should be established in all radiology departments to take the optimisation agenda forward. Communication between medical physicists, radiographers, and radiologists, as well as cardiologists and other radiological medical practitioners is key to achieving optimisation of imaging and establishing and reviewing clinical protocols. It is recommended that optimisation teams should be established for specific radiological areas (e.g. organ-specific sub-specialities in radiology practices), containing the leading expert available for each type of the more common procedures. Vendor application specialists should collaborate with the optimisation team in providing information on equipment operation throughout the life of the equipment, but especially during the commissioning phase, and ensure that any procedures using new techniques are optimised as soon as they are introduced. Support from an applications specialist should be seen as an integral part of the equipment investment, and included in the specification.

An approach of this type should support continuous improvement in radiological protection aspects of imaging protocols, but the arrangement will vary with the size of the organisation and requires enough resources to be allocated. For example, the radiological protection for any procedure will not be optimal unless referrals contain information about the clinical question, the radiologists have access to the relevant aspects of their patients' clinical histories, any prior imaging is available for comparison, and there is communication regarding patients' preferences for and ability to cooperate during the imaging procedure. Thus communication between the referring clinician and the radiologist is a key element in optimisation for individual patients that is essential for appropriate justification. As optimisation reaches more advanced levels, justification and optimisation start to become a continuum, rather than distinct processes. Since building optimisation teams requires resources, hospital management who determine staffing of the radiology service have a key role and need to ensure that all staff are appropriately trained and have sufficient resources, including time, to carry optimisation forward. In some countries there are no medical physicists in diagnostic radiology, and tasks that they would normally carry out come under the radiographers or external providers whose service is limited to technical equipment performance checks [8]. However, the involvement of qualified medical physicists, trained in diagnostic radiology or the modality in question, is considered essential and is a component of the move from level D to level C (figure 1).

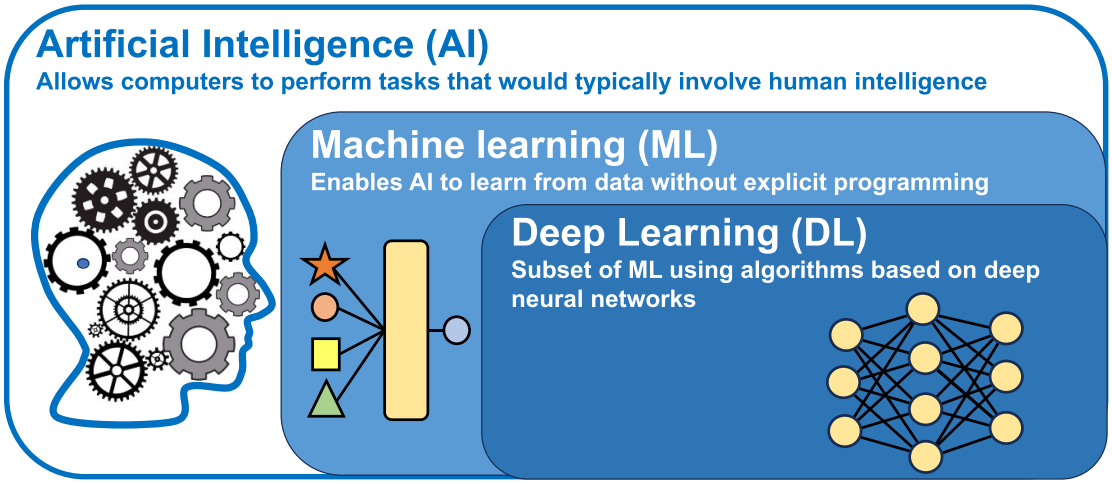

Figure 2. Conceptual hierarchy of artificial intelligence, machine learning and deep learning which enables a wide range of tasks to be performed using computer algorithms. In the context of radiological optimisation, this involves mostly application of deep learning. Thus, highly non-linear problems can be solved which are typically too complex to be managed with traditional computational models.

There have, in the past, often been traditional, hierarchical organisational structures, with cultures within professional groupings sometimes impeding close collaboration. There is a need to change these structures and move towards a more multi-disciplinary approach with tasks organised jointly, with regular interaction to encourage continuous improvement of knowledge and practice to deal with the fast-developing field of medical imaging. An important element in building mutual recognition and dialogue is adoption of a consistent, systematic approach, in which tasks are performed according to the same set of rules and principles and that the assignment of roles and responsibilities is set out clearly.

2.2. Methodology

The practical process of optimisation begins with developing an understanding of equipment performance and parameters related to patient dose, and this requires both access to appropriate tools for testing the equipment performance and a level of expertise in evaluating and understanding the implications of results. Only when measurements are made of dose parameters and surveys undertaken of patient doses will there be an indication of dose levels [4, 5]. Evidence of how doses in one hospital compare with those in others will only be obtained when patient doses are audited and comparisons made with diagnostic reference levels (DRLs) which should be established and updated periodically [9].

All imaging procedures should have associated clinical protocols, that have been prepared to assist in decision making about equipment settings, exposure levels and techniques. These should be set up using a team approach with imaging professionals working together. Evaluation of the clinical images together with analysis of results from equipment performance tests and surveys of patient doses should feed into the knowledge base to refine clinical protocols. The main aspects of this process are dependent on the skill and experience of all the imaging professionals, including the influence of training, and methods of improvement through self-evaluation. Many of the performance tests on imaging equipment used at the present time, such as resolution and contrast do not provide good mimics for clinical image interpretation tasks and these need to be improved. Moreover, such observational tasks performed by staff can be time consuming and subjective and more automation of imaging performance evaluation, for example by using model observers [7, 10, 11], could improve assessments and enable more detailed directed evaluations. In time, the aim would be to involve more patient-specific parameters linked to care outcomes with methods for evaluating image quality more relevant to clinical tasks being performed. Methods using artificial intelligence, machine learning and more specifically deep-learning (figure 2) are developing fast to satisfy requirements for these clinically relevant measurements [12–15]. These tools may provide more comprehensive methods for monitoring of imaging quality, organ segmentation and patient specific dose estimation, providing potential methods that can further improve optimisation.

Steps in the optimisation process need to be prioritised in terms of requirements for tools, facilities and expertise in practice, to set goals that can reasonably be achieved by radiology departments with the available resources. Steps will include basic exposure factor optimisation, adjustments to automatic exposure control (AEC) devices, and evaluations of equipment performance and patient dose. These should be followed by adjustments to equipment settings and where practicable software supported optimisation using dose

management systems that are patient-specific. Implementation of radiation exposure monitoring software is a useful tool for observing and comparing dose levels, raising the awareness of operators to dose levels prior to an exposure being made.

2.3. Processes

Tools and professional expertise to undertake optimisation of radiological protection are necessary but not sufficient. There needs to be the motivation and impetus to ensure tasks are performed, assessments and evaluations are made, and that these are considered in the development and adaptation of clinical protocols. Timing of equipment performance tests, including evaluation of image and dose parameters, can all be agreed, but there must be processes in place to ensure that these take place. This requires a management structure to provide the control and some form of quality management system to monitor and record the actions taken. The most important action is that results from tests and assessments carried out, together with radiologists' evaluations of clinical images, feed into the optimisation of imaging protocols.

When equipment is purchased acceptance tests should be carried out to ensure the equipment is safe and functions according to the vendor's specification. Commissioning is undertaken to check that the equipment is ready for clinical use and establish baseline performance values against which the results of routine Quality Control (QC) tests can be compared in the future (IAEA 2023b). Clinical protocols should be set up related to image acquisition with advice from the vendor's applications specialist and these should be evaluated during the commissioning phase by the optimisation team.

There has been much effort put into setting DRLs and corresponding typical values in recent years [9]. Collecting and comparing dose results from multiple departments is an interesting and useful exercise, but there is a risk that this can become the main goal for the core team. The setting of DRLs (be they national, regional or local) is one step, taken after the standardisation of examination protocols and initial steps in optimisation. The aim of a DRL is to help in identifying hospitals or examinations where further optimisation is required. National DRLs could be complemented by local DRLs to advance dose management aspects of optimisation on a local or organisational level. Once DRLs are in place they should form part of a process of audit, review and adjustment that looks continually to improve optimisation of radiological protection.

3. Levels of performance and approaches required for optimisation

The stages in development of the different aspects: the processes, methodology and professionalism are depicted in figure 3. The processes are shown on the left hand side, as the framework including the processes is seen as the driver, triggering the actions from the professionals once optimisation starts to be put in place, but the order in which the three components develop will depend on the resources and strengths of the local facility. Optimisation can be implemented through a step by step process and the levels D: Preliminary, C: Basic, B: Intermediate, and A: Advanced have been introduced to provide guidance to departments on what might be the next step for them to take (figure 1). Brief descriptions of the practices that might be followed in facilities at different levels are given in table 1. In the first ICRP report on optimisation, tables are included listing the criteria that should be fulfilled for attaining each level [7]. This will depend on the equipment, the technical infrastructure and tools available, staffing and levels of multi-professional expertise, prevalent clinical indications, and budgets.

Development of a coherent optimisation strategy is difficult to achieve in isolation, as the factors involved in the development, and the technical expertise all require education, training, and advice from experts. Sequences of actions setting out possible approaches that might be used to support progress of a facility to the next level are set out in the report, many of which utilise the experience of others, and some examples are given below.

D. Preliminary: (How to move toward level C)

i. Set up links with professionals in hospitals/facilities with more advanced QA programmes to mentor and exchange ideas.
ii. Employ, educate, and train all radiological staff, including medical physicists, in imaging science, technology, and practice, including optimisation techniques. This will typically be through attendance at external courses, but may include online training and visits to other facilities.
iii. Prepare and document clinical protocols using evidence from professional societies with assistance of radiological colleagues from other facilities and web resources of professional societies.
iv. Purchase equipment for measuring performance of x-ray equipment for individual facilities or groups of hospitals and introduce an appropriate QA programme.

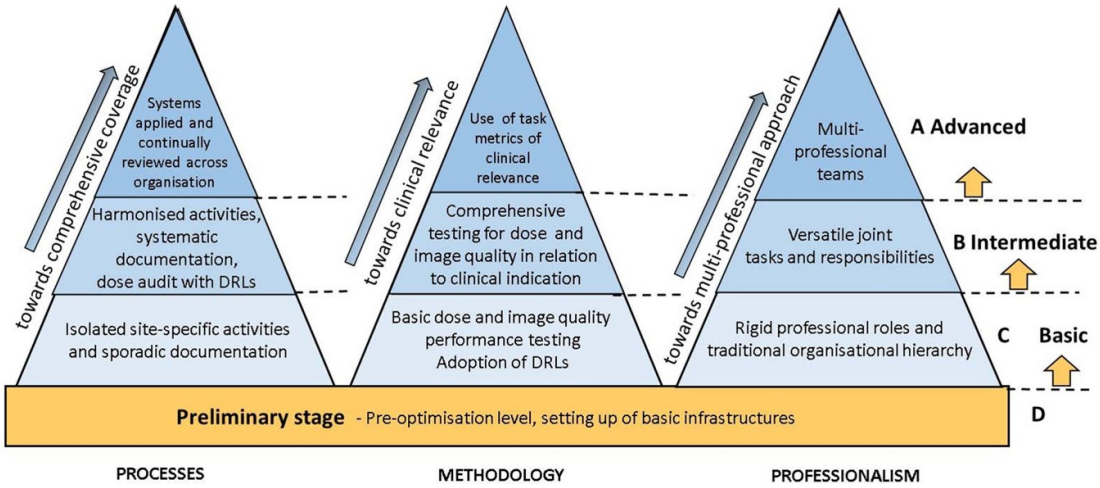

Figure 3. The three main components in the development and maturation of optimisation in the form of pyramids. The processes should ensure that optimisation tasks are performed. These utilise the methodology in the second pyramid and require the professional collaboration indicated by the final pyramid. The levels A-D represent different stages in achievement (table 1). The pyramids set out the arrangements that should be in place for the three components when each level is achieved. Figure reproduced with permission from ICRP [7].

Table 1. Arrangements and processes that might be expected to be in place for facilities that have achieved different levels of optimisation.

Level	Arrangements and processes
D. Preliminary	Isolated radiological professionals with little or no diagnostic radiology medical physics support. Assessment of image quality based only on evaluation of clinical images by radiological medical practitioner. Equipment performance tests carried out by radiographers or other healthcare professionals to meet regulatory compliance, but with limited organisational structure or documentation of procedures for implementation of optimisation.
C. Basic	Radiological imaging professionals including medical physicists appointed, but exposure factors based on historical practices. Centres developing expertise in performance testing, but arrangements for both testing and patient dose surveys are *ad hoc*, with limited feedback of results to other radiological professionals. Early stages of co-ordinating performance testing by medical physicists and documenting procedures.
B. Intermediate	Knowledge of optimisation practices widespread but may not be put into practice in all centres. Surveys of patient doses for major examinations carried out, feeding into evidence based preparation of protocols. Optimisation teams comprising radiographers, radiological medical practitioners, and medical physicists established to review and optimise protocols, and establish DRLs for some modalities.
A. Advanced	Levels of image quality delivered that are optimal for specific clinical imaging tasks agreed by all reviewers. Multidisciplinary optimisation teams regularly analyse radiological images and improve protocols based on experience. Continual live review and optimisation of imaging protocols based on analysis of acquisition parameters and patient-specific dose parameters using radiation exposure monitoring software. Gradual development of image quality parameters and their assessment methods to enable objective, quantitative and automated image quality monitoring corresponding to clinical tasks.

C. Basic:

i. Ensure all referral requests follow established referral guidelines and contain sufficient information about the clinical question to support further optimisation.
ii. Arrange review of protocols by small team of national or international experts to assess level of optimisation and identify where effort is required. Such an exercise could involve a workshop with input and training of staff from a number of centres.
iii. Carry out initial small-scale survey of patient doses in most general and relevant examinations to establish level of optimisation already in place.
iv. Aim to train a multidisciplinary group of local professionals in optimisation requirements through attendance at courses and collaboration with centres with more advanced quality systems, infrastructures and imaging processes.

B. Intermediate:

i. Provide referral guidelines to all referrers for guidance to support further optimisation.
ii. Contribute results to national surveys of patient doses to determine how local doses compare with other centres and evaluate the level of optimisation. Results from national surveys can be used to establish DRLs and median dose levels.
iii. Set up optimisation teams comprising radiographers, radiologists or other radiological medical practitioners, and medical physicists for each modality to review and optimise clinical protocols.
iv. Arrange advanced training courses in optimisation techniques for members of optimisation teams and provide cascade training for other radiology staff.

A. Advanced:

i. Participate in national surveys of patient doses for all types of x-ray modality to enable up-to-date DRLs and median dose levels to be maintained to aid in optimisation with possible utilisation of national dose registries.
ii. Promote continual sharing of published literature and experiences in optimisation techniques in order to maintain the level of optimisation and ensure procedures using new techniques are optimised as soon as they are introduced.
iii. Implement more clinically relevant assessment of image quality (e.g. with model observers to achieve objective quantification of clinical image quality), as they become available.
iv. Utilise integrated QA systems for protocol and equipment management to enable more consistent quality from the technical to the clinical level.

Quality management systems provide a framework that can facilitate a systematic organisational approach, through providing signals to trigger actions and monitoring whether goals are achieved.

4. Analysis of patient dose and image quality

The choice of exposure factors will influence both dose and image quality and depends on the patient, the clinical question, the examination, the equipment used to image the patient, the operator performing the procedure and the person interpreting the image. Knowledge of the doses delivered to patients by imaging is gained through surveys of doses to real patients and is essential in the development and implementation of a dose management strategy. The results of a patient dose survey can be audited by comparison against the national DRL or other published DRL values. It is now possible to retrieve dose data from radiology information systems (RISs) or patient radiation exposure monitoring/management systems and this can enable all patients examined to be included in dose surveys. Dose and other patient data are input into RISs manually and so they are prone to transcription errors, whereas data are taken directly into dose managements systems from imaging equipment and some also provide alert systems to radiation protection professionals responsible for tracking high or low patient exposures. Use of such systems can allow automation of patient dose data collection and aid in streamlining the dose analysis and audit process [4].

Knowledge and feedback of patient dose information should be a common interest among all staff involved in x-ray imaging examinations. This multi-disciplinary team approach helps to ensure that results of dose monitoring and any consequent changes that need to be made are fed back to equipment operators. However, patient dose audit against DRLs will only contribute to optimisation if it leads to corrective actions when unnecessarily high doses levels are observed, or trigger clinical image quality evaluation if exceptionally low dose levels are observed.

The image quality in medical imaging relates to the capability of providing anatomical or functional information that enables accurate diagnosis and informs care decisions. It depends on physical characteristics of the imaging system and the interpreter who reviews the images. Basic image quality is characterised by contrast, resolution and noise and can be assessed through QC tests. Contrast and resolution describe how different targets are represented in greyscale and sharpness, while noise affects image texture and the visual detection of features. Subjective evaluation of clinical image quality by radiological medical practitioners forms part of the routine self-assessment process included in the QA programme of a radiological department. Anthropomorphic phantoms mimicking patient tissue attenuations, morphometry, organ distribution and tissue texture can be used together with appropriate image quality metrics in protocol optimisation using arrangements that closely resemble the clinical setup. Artificial intelligence and its subsets (figure 2) are likely to provide versatile methods for a range of optimisation related tasks in the future, including image quality estimation directly from clinical data.

5. Staffing level, training and education of staff

The key elements in running a radiology imaging service are having and using the appropriate equipment, and having staff running the service with the knowledge and experience to make proper use of the equipment. Therefore, the staffing level must be adequate and all the staff, i.e. radiographers, radiologists and other radiological medical practitioners, and medical physicists, need to have the knowledge, skills, and competencies to contribute effectively to the work of the optimisation team. Imaging staff should have undertaken appropriate university or college education, training and certification, but training should continue throughout their working life with a commitment to continuous professional development. This is especially important when investment in new imaging equipment and software is being planned to ensure that staff members have an understanding of optimisation techniques specifically available with the new imaging systems as they are implemented in clinical use.

Training programmes can be provided by professional societies and educational institutions. Vendors of imaging equipment and software should produce updated training material when new systems are introduced to promote optimisation. Web-based packages and equipment simulation platforms can be made available to improve access to training material and learning schemes that are independent of time and location. These could play a significant role in modern imaging facilities with strong backgrounds in digital learning environments, but may also provide a novel training channel for facilities in developing countries with fewer resources. Optimisation training within individual departments should be given by multi-disciplinary teams, which can help to build multi-professional team culture and promote effective communication. Provision of training should be supported by legislation and regulatory authorities prompting medical facilities to invest in training of staff in optimisation techniques.

6. Optimisation techniques for digital imaging modalities

The general principles of optimisation apply to all digital radiology equipment, but the ways in which they are implemented depend on the modality. The second ICRP report on optimisation in digital radiology, which will be published as a follow up to the first, deals with the individual digital radiology imaging modalities, and also considers the imaging of paediatric patients and pregnant patients.

During the clinical use of imaging equipment, the impact that exposure parameters have on patient dose may go undetected, unless dose levels are monitored, and may result in the routine delivery of dose levels that are higher than necessary. Continuous monitoring of dose quantities on each modality and (indication specific) examination protocol helps to identify any issues at an early stage. The imaging protocols in all modalities should be reviewed and revised periodically, taking account of data on clinical image quality and results from dose audit. Collection and analysis of dose data using radiation exposure monitoring systems may enable more timely feedback of results so that both focused training of radiological professionals and changes to improve protocols can be implemented at regular intervals.

For radiographic imaging, appropriate exposure factors, tube voltage (kV), added filtration and tube current time product (mAs) adjusted by AEC methods should be established for different anatomical regions and patient characteristics, especially patient size, linked to the clinical question, and these should be recorded in protocols. AEC devices should be calibrated during commissioning to suit the characteristics of the detector, as the energy sensitivities of phosphors used for digital radiography vary in different ways.

Fluoroscopy systems are available in a variety of configurations and incorporate a complex set of equipment design features that should be properly selected, with proper training of the operator, and configured protocols considering the image quality requirements for the procedures commonly performed with a particular type of equipment [16, 17]. The automatic dose rate control adjusts exposure parameters and incident air kerma rate at the image receptor automatically, to deliver a constant signal intensity and aims to give a consistent signal to noise ratio in the image. The exposure options can also include the incorporation of additional spectrum shaping filters usually made of copper, to remove low-energy photons thus reducing the absorbed dose to skin and superficial tissues, but also to increase image contrast by shaping the x-ray spectrum to match the k-absorption edge of barium or iodine used as contrast media. Modern fluoroscopy systems operate in pulsed fluoroscopy and other acquisition modes with several pulse rate options. The lowest pulse rate should be used to obtain images of acceptable quality for the imaging task, e.g. rapidly moving organs (e.g. heart) might require higher pulse rates with or without added magnification (preferably digital zoom without traditional zoom dose penalty). The variety of the equipment features should be well known and used by the staff operating the equipment to achieve the clinical task with the minimum possible radiation exposure, especially in more complex bi-plane interventional procedures. Staff exposure is a factor that should also be considered in optimisation for fluoroscopy.

Optimisation for CT involves appropriate selection of several scanning parameters and requires an understanding of their interdependence. Dose reduction features are available, such as automatic tube current modulation and automatic tube voltage selection. Both features aim to achieve optimal and consistent image quality and account for the differences in patient size, attenuation, and iodine contrast enhancement in a patient specific manner. Methods of CT image reconstruction, developed as computing power has increased, provide improved levels of image quality. Iterative reconstruction is used routinely and new methods using deep learning-based image reconstruction or restoration are becoming available. The potential to improve image quality can be used indirectly in the optimisation process to lower the dose and maintain a similar level of image quality. Many CT scan dose reduction or image quality improvement features have been facilitated by new hardware and software applications such as use of virtual non-contrast imaging, dual energy CT [18] and photon counting CT [19]. Other features that aid optimisation are increased imaging speed, optimal timing of contrast scans (resulting in reduced dose level or contrast volume), more accurate and consistent patient centring using 3D cameras, and AI-based algorithms at various stages of the CT scan process [20, 21]. Amidst these various applications which can enable optimisation of scans to be improved it is essential that staff are properly trained in order to apply the new features effectively and safely. On the other hand, the correct operation of these technical features must be ensured through regular review and performance tests [22].

7. Optimisation for individual patients

With the increasing focus on precision medicine and individual-based treatments, optimisation requires adjustment of protocols and exposure parameters for individual patients and groups of patients with similar conditions. Optimisation (and justification) in children's imaging care must be given special consideration due to their higher radiosensitivity, the differences in physiology and clinical conditions from adults, the wide range in body size, and the challenges of communication and cooperation. Patient age is a poor predictor of a child's body size and measurement of body thickness is ideal for use in protocol development for the trunk. However, thickness is not generally available, and weight is preferable to a child's age for assessing exposure requirements involving the trunk in all radiological modalities, whereas age is more appropriate for examinations of the head. Since children are not just smaller versions of adults, staff carrying out and interpreting paediatric imaging procedures must be trained in specific paediatric procedures and understand the ability of the patient to cooperate. There are key technique factors, as well as the size, that influence the exposure and in projection imaging these include the use of a grid (not typically necessary in small children) and the importance of collimation due to potential nearness of radiosensitive organs to the field being imaged for children. Referring clinicians must know what alternative non-ionising radiation examinations, which are available locally, are suitable for different clinical indications [23, 24]. The core team of radiological professionals must have specific education and training in optimisation techniques for imaging infants and children. In addition, the referring clinicians, parents, carers and children must be given sufficient understanding of the imaging procedure preparation, duration, benefits and risks–which can be through use of information leaflets and web aids, to allow them to be involved in the decision-making process when appropriate [25]. The shared decisions apply from the time when imaging is being considered, through performance of the examination, the diagnosis, and decisions about management of the patient.

A detailed consideration of justification is required for medical exposure of pregnant patients, that weighs the benefits and risks to both mother and the unborn child. As with children, imaging methods using non-ionising radiations, such as ultrasound or magnetic resonance imaging should be considered, if these can achieve the clinical purpose. However, the general radiological protection aims are the same with all patients regardless of patient age or the possibility of pregnancy. These are limiting the exposure only to the appropriate anatomical region and the use of optimised protocols—fitted to each indication and utilising available technical and automated features to adjust scan parameters to each patient. Specific to pregnant patients, this can help to avoid direct irradiation of the embryo/foetus and lower the overall exposure to mother and unborn child regardless of the applied x-ray modality.

Finally, there is a need to consider the current rapid rates of approval for new AI/ML tools and how these might develop into the future. Algorithms for deep learning image reconstruction and other applications are trained in the factory with patients that may not fully represent the local patient cohorts, so local validations may be required with varying scan parameters and this will involve requirements for explicit rules around data access, usage, monitoring and local governance [26]. As new technical and digital techniques become available to improve optimisation of the various x-ray imaging modalities and examination types, this creates a momentum for merging optimisation more closely with the justification process as a data-driven approach. More specifically, integration of evidence-based referral guidelines into hospital information systems and radiological information systems in a form of electronic clinical decision support can then help to direct

patients to the appropriate modalities and examination types, at the right time [4]. When this is linked to the access and availability of local imaging equipment with optimised scan protocols, the processes of justification and optimisation become a comprehensive undertaking of maximising diagnostic benefit/risk for the patient. The data can also be reviewed and compared at a facility or individual physician level to assess patient outcomes (justification) as well as with regard to utilisation of a given imaging procedure (for a stated clinical indication).

8. Conclusions

ICRP Publication XX [7] describes a strategic framework to assist radiology and management staff in optimising radiological protection for imaging in a facility. This report sets out the overall vision to aid implementation and a second report deals with practical aspects for the main digital radiology modalities (radiography, fluoroscopy, and CT). The different aspects involved in the optimisation process are: Professionalism—multi-professional and multimodal team work, Methodology—tools for equipment performance monitoring, effective testing methods, and dose audits, and Processes—harmonised and systematic activities, consistent documentation, and quality systems that trigger actions. The foundation is based on collaboration between radiological professionals, with radiological medical practitioners, radiographers and medical physicists working together as a team within an organisation that provides a structure for implementing the processes. Each should feed in results from their practice and measurements to continually develop, improve and optimise protocols. Successful collaboration depends on imaging professionals within the optimisation team working closely together in their different roles, while recognising the skills of their colleagues. Management needs to recognise and support the provision of education and training, with adequate training from vendors on proper use of new features, that allow image quality to be improved and dose levels to be reduced when practicable.

Operation of all digital radiology imaging involves the need for an understanding of the interdependence of patient dose and image quality. There is, however, a risk of dose creep with digital imaging technologies that it is important to recognise. Significantly higher doses can occur unnecessarily, unless a strong quality and dose management system is in place with trained radiological protection professionals. In order to make full use of new technological and software features, the performance of equipment needs to be monitored and analysed, and the results fed into the refining of examination protocols. Patient dose audit is an essential tool in the process, but so are checks on image quality, and dose should not be reduced to a level that affects the diagnostic quality of the images. Optimisation should be seen as a continual process that is an integral part of imaging and is an essential requirement for all efficient digital radiology services.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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