Committee on Medical Aspects of Radiation in the Environment (COMARE)

Eighteenth report

Medical radiation dose issues associated with dual-energy X-ray absorptiometry (DXA) scans for sports performance assessments and other non-medical practices.

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Preface

i. The Committee on Medical Aspects of Radiation in the Environment (COMARE) is a Department of Health and Social Care expert committee that provides independent expert advice to the UK Government on the health effects of natural and man-made radiation. In over 30 years the committee has provided advice on a range of issues from childhood cancer clusters in the vicinity of nuclear installations to sunbeds and to radiation doses resulting from the use of computed tomography (CT) in the UK.

ii. The aim of this COMARE report is to provide advice to the Department of Health and Social Care (DHSC) on the issues associated with the use of dual-energy X-ray absorptiometry (DXA) scans for sports performance assessments and other non-medical uses. This report reviews the justification of these practices, with consideration of the potential benefits and risks to the individual. Recommendations are provided for the use of DXA scanning for sports performance assessments. However, it has not been possible to provide these for other non-medical uses as the committee were unable to find any reports of other applications. An approach for a review of evidence for future justification of other potential non-medical practices is proposed.

Lay summary

Background

S.1 Dual-energy X-ray absorptiometry (DXA) is a technique involving ionising radiation used to measure body composition: specifically the proportion of fat, bone and muscle in a human body. DXA is also the standard method for making diagnoses of osteoporosis.

S.2 Athletes across a range of events and sports attempt to adjust and/or manage their body weight to maximise their performance. For a given event, there is a tight relationship between performance and body composition. Body composition can also vary in athletes over a competitive season. The different training regimes and diets employed by athletes result in changes to the composition of the body tissues. An effective tool to measure these changes could enable athletes and their trainers to gain a better understanding of the effects that occur, how these are influenced by training and diet, and how they impact on performance.

S.3 Body composition and body weight are key factors in sports where there are weight classifications. Historic practices applied to lose body weight can have adverse effects not only on the performance, but also on the health of athletes. Techniques to evaluate body composition could inform decisions about the ability of athletes to perform in designated weight categories.

S.4 In recent years DXA has been used in studies assessing the proportions of fat and lean tissue for sportsmen and sportswomen in relation to their sporting performance, both in the UK and in other parts of the world. Although these studies have largely been undertaken as research projects or as medical referrals for a clinical need, there are reports of the use of DXA on professional athletes simply in relation to sporting performance. DXA scans are also being offered commercially to the general public for assessment of body composition.

DXA scans for sports performance assessments

S.5 The Department of Health and Social Care asked COMARE to review the evidence on the practice of using DXA scans for sports performance assessments within the UK. COMARE established a Medical Practices Subcommittee (DXA) for this work, with the terms of reference:

> "*To advise COMARE on the health effects, benefits and risks arising from the use of ionising radiation in DXA in non-medical practices through assessment of the available data and to inform COMARE of further research priorities*."

S.6 In producing this report, the subcommittee reviewed the value of using DXA for sports performance assessments, and the benefits it provides for individual athletes, their teams and society at large. The committee was unable to find evidence of the use of DXA for other non-medical purposes.

Conclusions

S.7 If assessment of body composition can aid in the improvement of sporting performance, this may benefit the well-being of individual athletes and the morale of the team, but at the present time there is no direct evidence that such assessments can improve sporting performance. However, a tool that enables athletes and their trainers to monitor and gain a better understanding of the effects on the body of training and dietary regimes could be beneficial. DXA is only one of several techniques available for such assessments and, if they are to be made, consideration should be given to the most appropriate method to be used.

S.8 Whole body DXA scans for determining body composition can be conducted quickly and are not demanding on the participant. Alternative specialised laboratory-based techniques requiring specific expertise (Chapter 4) may provide better accuracy for assessing change than older DXA scanners, although improved reproducibility has been reported in newer DXA scanners for medical applications. For DXA scans, there is no standardisation between manufacturers in the calculation of results, and values may vary between different scanner makes and models. Standardisation of measurement conditions is required in order to achieve the necessary accuracy for evaluation of body composition. For example, precision error in the measurements is increased by exercise or eating and drinking prior to measurement.

S.9 There is a moderate amount of evidence available on the use of DXA scans in elite athlete populations at the present time; however, further research is required to develop a robust evidence-base, particularly on the accuracy of imaging and optimised exposure levels.

S.10 The use of DXA scans as a tool for following body composition during a training programme suggests the requirement for repeat assessments to determine changes, and, if the individual continues to participate in sport, this could extend over several years. Although the radiation dose level of single whole body scans is minimal (effective doses in the range of 2-10 μSv), individuals may receive cumulative doses from multiple scans. Consideration should be given to the cumulative effect of multiple exposures over several years as part of a training programme. This is particularly relevant for those younger sportsmen and sportswomen, for whom the individual risk from exposures may be slightly greater than in the population as a whole.

S.11 There is the possibility that the practice could be expanded into mainstream sporting activities, such as fitness programmes for individuals and sports programmes in schools. Although potential benefits may accrue from the use of DXA scans in controlled situations, as part of well-designed programmes of athlete training or nutrition, it is important that any more widespread use of DXA scanning by the sports/fitness industry should be carried out by properly accredited individuals. There is currently no convincing evidence that wide-scale availability of the technique in sports clubs is likely to yield any benefit. Any radiation exposure should be kept as low as reasonably achievable, so good practice dictates that appropriate measures are taken to justify any exposure and ensure that the delivery is optimised to minimize the dose to the exposed individuals.

S.12 The committee is aware that there may be other potential applications of DXA for assessments linked to nutrition and for the beauty industry. In addition, commercial companies are offering DXA scans to the general public to track changes in their fat and lean tissue. However, there is insufficient information currently available about these applications, thus if DXA scanning is to be used more widely there is a need for properly constituted research studies to be carried out. Consequently it was impossible for the committee to evaluate the justification for these potential practices.

S.13 Based on the evidence reviewed in this report, COMARE has made a number of recommendations (Chapter 8) and the key points are summarised below.

Key points of COMARE's recommendations

1. COMARE recommends that the practice of using DXA scans for the assessment of body composition in relation to sporting performance could be justified, but only as part of a recognised training programme. The committee also recommends further steps for consideration when undertaking such assessments on individual athletes, including limiting both the number of scans given to an individual in one year and the time interval between scans. Particular care should be taken when considering programmes involving children under 16 years of age. Alternative techniques are also available and it should be determined whether DXA is the most appropriate technique to use for the assessment in each programme.

2. COMARE recommends the establishment of an evaluation requirement for the imaging and dose performance of DXA scanning equipment following installation. The evaluation should ideally include the suitability of any scanner in terms of the accuracy in assessment of changes in fat/muscle composition and measurements of the entrance surface dose levels for different examinations. Consideration could be given to the requirement of periodic calibration of DXA equipment for assurance of imaging and dose performance when used for sports performance assessments.

3. COMARE recommends that, as part of the consent procedure, approval should be sought from the individual examined regarding action to be taken should there be any incidental findings unrelated to the scan's purpose. This would include informing the individual concerned and a requirement that the image and resultant report be referred to a medical doctor, who could review the information and determine whether further investigation was appropriate.

4. COMARE recommends further research studies on the assessment of body composition by DXA and the use of DXA examinations for sports performance assessments and other non-medical uses. Further studies would provide information on the accuracy of DXA scanner models and software versions and also data on scan parameters, exposure levels and scanned areas of the body in the evaluation of body composition. Results on body composition and sporting performance should be analysed carefully and collated to extend the knowledge base required to assess benefit.

5. COMARE recommends the establishment of an evaluation process for any future applications involving the use of alternative radiation imaging techniques in addressing non-medical questions. The evaluation should include identifying the potential benefits of any technique and a risk assessment including dosimetry data.

6. COMARE recommends that particular consideration is given by the relevant authorities to the use of DXA scanning for body composition measurement in relation to sporting performance and other recreational or commercial activities by all organisations, including commercial companies.

Chapter 1: Introduction

DXA scans

1.1 Dual-energy X-ray absorptiometry (DXA) is used in medicine to measure body composition and is one of the most widely used techniques for non-invasive assessment of bone integrity. It is the standard diagnostic tool for measuring / monitoring bone mineral density in patients who suffer with osteoporosis and are, therefore, at increased risk of bone fracture.

1.2 In recent years DXA has been used in sports medicine and sports science for the assessment of athletes' bone health and their response to training (Mattila et al, 2007; FSEM, 2015; Nana et al, 2015) and has been applied in assessing proportions of fat and lean tissue for sportsmen and sportswomen in relation to their sporting performance, both in the UK and in other parts of the world. These studies have largely been undertaken for research purposes, but there are reports of the use of DXA on professional athletes. The potential benefits to the individual from DXA assessments are linked to management of their sporting performance and monitoring of body composition changes in response to diet and training regimens, while benefits to their team relate to performance in sports competitions. The dose per exposure is minimal, typically about 10 µSv effective dose. This practice can only be undertaken legally in the UK at the present time if it forms part of a biomedical research project or is classed as a medical exposure.

1.3 All practices that involve the deliberate exposure of persons to ionising radiation are required to be justified according to the Justification of Practices Involving Ionising Radiation Regulations 2004 (JoPIIRR, 2004). Exposures of persons for the purposes of medical diagnosis, treatment or research are justified under this legislation. However, a gap in current UK regulatory control has been identified concerning the justification of medical X-ray techniques used for the practice of sports performance assessment as a non-medical exposure, not part of a research study. There is currently insufficient evidence on the value of this application of the technique to make a decision as to whether such practices should be justified under JoPIIRR. Therefore, DHSC has asked COMARE to review the evidence on the risks and potential benefits, in addition to other aspects.

1.4 The Ionising Radiation (Medical Exposures) Regulations 2017 (IR(ME)R, 2017) applies to both medical and non-medical exposures from the use of medical radiological equipment. Consequently, justified uses of medical X-ray techniques for the practice of sports performance assessment are now regulated by IR(ME)R 2017.

1.5 This report considers the value of the practice of the use of DXA in relation to sports performance assessment in terms of the potential benefits it could provide for individual athletes, their teams and society at large. There is limited evidence underpinning the use of DXA in elite athlete populations at the present time, so further research is required to develop a robust evidence-base. Although the dose level of individual scans is minimal, consideration needs also to be given to cumulative doses that could arise from multiple scans and from the uncontrolled proliferation of the practice in mainstream activities, such as fitness programmes of individuals and sports programmes in schools. Commercial companies in the UK are currently offering DXA scans to the public to track changes in their fat and lean tissue. This document considers whether the practice of using DXA for sports performance assessment should be justified based on the limited evidence, addresses the need for controls on the use and dose levels involved, and provides recommendations on required guidelines, taking account of current evidence while a more robust evidence-base is being developed.

1.6 The committee is aware of other potential applications of DXA e.g. in the nutrition and beauty industries; however there is very limited evidence for these practices, making evaluation of these potential uses currently impossible. In addition, alternative radiological imaging procedures have been proposed for different types of non-medical assessment of sporting potential or performance (e.g. bone age assessment for young sports persons) which are outside the scope of this review. Identification of a process to evaluate all proposed uses of radiation-based imaging techniques is considered.

Chapter 2: DXA equipment and information given on body composition

DXA equipment

2.1 DXA originated from the more basic radionuclide-based techniques of single photon absorptiometry (SPA) and dual photon absorptiometry (DPA) developed in the 1960s and 1980s respectively. The current DXA machines use X-rays produced in a vacuum tube.

2.2 The basic principle of DXA equipment is to make a transmission measurement through the patient using a pencil or fan beam of X-rays or γ-rays of differing energy or spectra. In most cases the patient is positioned supine on the scanner couch whilst the fan beam and detector assembly moves over the patient. The X-ray source is generally positioned below the patient and the detectors above the patient, although some scanners can perform lateral scans with the patient lying in a supine position. The difference in X-ray beam transmission of the two beams or spectra together with a model of the molecular content of each tissue type and their transmission properties are used to calculate the amount of material by specific tissue compartment. Typical values of X-ray tube voltages used for the comparison in fan beam DXA scanners are 70-75 kV and 130-140 kV.

2.3 For the purposes of bone densitometry, the scan can cover all or specific parts of the body, e.g. spine, neck of femur or wrist etc. However, for assessment of body composition, scans would generally be of the whole body, although scans of the limbs might be undertaken for specific applications. The data would be presented as a two-dimensional pixel map of composition, together with numerical data on total body fat and lean percentages, regional composition (e.g. for arms, legs and trunk), bone density, muscle symmetry, etc.

2.4 Variables influencing the radiation dose delivered to the individual being scanned are the entrance surface dose, determined by the tube current and exposure time, and the size of the field scanned. For bone densitometry measurements, normal practice is for whole body scans to use lower tube current and dose rate values than scans of particular parts of the body. For body composition measurements, the scans are likely to be whole body or limbs, so field sizes are unlikely to vary significantly. Since composition is assessed from a comparison of two X-ray beams with fixed tube potentials (kVs), the same values will be used for patients of all sizes.

2.5 As DXA typically uses the spectra from two different X-ray beams or separates a single beam into two energy measurements, it is only possible to determine the composition of two compartments directly at each pixel scanned. To determine the components of a three compartment model a proprietary algorithm must be used to make these assessments. The body is generally split into fat, non-fat and bone compartments, although others could be used. In general, this determination is achieved by measuring the composition when only two out of the three components are present and using this information to infer the third component. For example, the fat and non-fat components in areas of the body that do not contain bone can be measured directly and this information can be used to interpolate the composition in the areas of the body that do contain bone.

2.6 One limitation of using DXA to measure the content of three compartments is that there is no standardisation of the algorithms used between manufacturers nor the models to determine the components beyond two compartments. This means that measurements made on different units may give different results despite the same body composition. Ideally, the same scanner model and software version would be used when undertaking serial measurements of the same subject and even the same scanner when the highest level of achievable accuracy is required (see Chapter 4).

Applications of DXA

2.7 The main clinical applications of DXA are in bone mineral measurements for assessing osteoporosis and the response to treatment for osteoporosis. Scans carried out in relation to osteoporosis use normal clinical ranges to assess the disease. DXA is also used to determine body composition for clinical research studies to assess the effects of interventions. Since DXA provides information on body composition it can, therefore, be used to assess patients with eating disorders and other nutritional problems.

2.8 The facility for members of the public to purchase DXA scans to assess their own fat and muscle body composition has been available for some time in the USA and similar services have recently been advertised in the UK press.

Derived values from DXA

2.9 **Bone mineral density** (BMD) is the bone mass in a defined area divided by the bone area in the same region, e.g. the femoral neck.

2.10 **Energy deficit** is a value derived from the change in total body fat and lean tissue. The scanner makes assumptions about the calorific value of tissue components, e.g. fat provides 39.5 MJ per kg and fat free mass provides 7.6 MJ per kg.

2.11 **Body weight** is where the total mass is calculated from all body regions. This can be used to compare results with the body weight measured using conventional scales.

2.12 **Muscle mass balance** is a measurement that compares the muscle mass on each side of the body. In some sports it may be beneficial to have muscles that are balanced in terms of size or strength on both sides of the body. However, DXA can only measure muscle mass and not muscle strength.

2.13 **Relative skeletal muscle mass** is where the lean soft tissue and fat mass is measured, usually in the appendicular skeleton due to the abundance of skeletal muscle and the clearly delineated bone regions. The technique can be used for conditions such as sarcopenia, which is more common in advancing age, where progressive and generalised decline of skeletal muscle mass and strength is observed.

2.14 **Fat distribution** can be measured using defined regions of interest. Such an analysis can be used to assess the amounts of android and gynoid fat. The relative amounts of each can be used to assess the risk of diabetes or heart disease.

2.15 **Visceral and subcutaneous fat** measurement techniques are still emerging and not many are yet in clinical use.

2.16 **Body composition changes** over time can be assessed using DXA. Consideration of the accuracy and precision of the direct and derived measurements are extremely important to determine minimum detectable change. The effects of changes in body composition, especially cellular water, on the utility of the measurements need careful consideration.

Current use of DXA in elite sport

2.17 The majority of evidence currently available on DXA scanning for sports performance assessments is from Olympic and Paralympic sport.

Table 2.1 - DXA use in Olympic and Paralympic sport in the UK

Sport	Frequency	How is it accessed	How is it used?
Short Track Speed Skating	4 times per year	Research study in collaboration with Nottingham Trent University.	The data are used to track changes in body composition in response to training.
Boxing	Ad hoc	Medical referral in response to need.	To assess bone health.
Athletics	Ad hoc	Medical referral in response to need.	To assess bone health.
Cycling	Ad hoc	Using private medical facility Manchester Institute of Health and Performance.	To assess the effects of training on body composition, muscle mass in particular.
Hockey	Ad hoc	Medical referral in response to need.	To assess bone health.
Sport Wales	Ad hoc	Medical referral in response to need.	To assess bone health.
Cricket	Ad hoc	Research study in collaboration with Loughborough University.	To assess bone health

2.18 Using the UK network of nutritionists within the Olympic and Paralympic world class programmes, information was collected on the current use of DXA for body composition or bone assessments and applications are listed in Table 2.1. These applications are limited and it is understood that the majority involve either the use of appropriate medical referral pathways in response to a clinical need or are linked to research studies. Information could not be obtained from professional football or rugby programmes prior to the submission of this report.

2.19 Meyer et al (2013) undertook a survey on behalf of the International Olympic Committee Medical Commission on the use of body composition assessment in sport. The survey received 216 responses from 33 countries and showed that skinfold assessment techniques were the most common method of assessing body composition. DXA was the second most common technique, with 38% of respondents indicating they assessed body composition using DXA.

Chapter 3: Evidence for a link between sporting performance and body composition

Body composition and sport performance

3.1 Body mass can be a key component in elite sporting performance. Athletes across a range of events and sports attempt to manipulate their body weight to maximise their performance. Track running can act as a model for many sports due to its range of events and distances. As a rule, there is a general reduction in body mass as the event distance increases, e.g. a marathon runner will be lighter than a 100m sprinter. Even within a given distance there will be a tight relationship between performance and body composition. In particular, variability between the Body Mass Index (BMI) of elite athletes decreases as their speed increases and performance improves (Sedeaud et al, 2014).

3.2 The relationship between body composition and performance differs depending on the event. For sprint-based events there is a clear link between muscle mass and force production (Maughan et al, 1983). In 98 competitive male sprinters, those athletes who were in the top third of 100m sprinting performance had significantly greater upper arm, thigh and calf girths indicating greater muscle mass than those in the slowest third (Barbieri et al, 2017).

3.3 For more endurance-based events a smaller size leads to more efficient heat dissipation (O'Connor et al, 2007) and reduction in energy cost of exercise (Deitrick, 1991). Small differences in size can make large differences in performance. Haakonssen et al (2016) analysed anthropometric profiles in 126 female cyclists, grouping them into world class, elite or sub elite according to their performance level. World class cyclists were just 0.6 kg lighter than elite cyclists and had a 2.7% lower body fat percentage.

3.4 Analysis of endurance running performance showed that calf girth can be a key component of running economy. Lucia et al (2006) showed that calf girth in elite Eritrean runners, with excellent running economy, was smaller (30.9 ± 1.5 cm vs 33.9 ± 2.0 cm) than elite Spanish runners, who had a poorer running economy. This effect is likely due to the moment of inertia being lower with a lower muscle mass in the calf.

3.5 Body composition, and in particular body weight, are key factors in sports such as boxing and judo where there are weight classifications. To compete in these events athletes must be between set body weights. For instance, in the Rio Olympic Games boxers competed at ten different body weight classifications (see Table 3.1). In these cases a tool that allows accurate assessment of body composition may inform decisions about the ability of athletes to be able to perform within specified weight categories.

3.6 Some historic practices to alter weight in sports like boxing and mixed martial arts have been alarming and harmful to athletes' health (Crighton et al, 2016).

Examples of these practices include excessive dehydration using saunas, diuretic use and extremely low calorie diets combined with high energy expenditures to lose body weight. DXA is used in the assessment of lean body mass and fat mass. The inclusion of fat mass gives the athlete and their support team information with regard to safe weight loss possibilities. Therefore, having a more accurate tool to monitor and assess body composition could assist athletes' efforts to lose weight appropriately. This could help athletes to understand the effects of training and diet, and aid in reducing weight management practices that may have adverse effects on athletes' health.

Table 3.1: Weight classifications in the Rio 2016 Olympic Boxing tournament

Classification	Body Weight Range (kg)
Super Heavy Weight	91+
Heavy Weight	81-91
Light Heavy weight	75-81
Middleweight	69-75
Welterweight	64-69
Light Welterweight	60-64
Lightweight	56-60
Bantamweight	52-56
Flyweight	49-52
Light Flyweight	46-49

3.7 The use of practices to aid weight loss is seen not only in weight category sports like boxing, but other weight sensitive events such as horse racing (Wilson et al, 2014). Chronic low energy availability can lead to decreases in performance and affect health and is a relatively common condition termed Relative Energy Deficiency in Sport (RED-S). The syndrome was first described by Mountjoy et al (2014), and includes the condition previously termed the female athlete triad. It describes a range of effects of low energy availability due to diet and exercise. More detailed knowledge of body composition may help to understand and avoid these effects.

Influence of training on body composition

3.8 Athletic training leads to adaptive responses to the given training load. The body adapts to the training provided and the diet consumed, both of which interact to affect body composition. For example, lifting heavy weights leads to muscle hypertrophy (Phillips, 2014), which is further increased when combined with dietary protein supplementation (Cermak et al, 2012), and reducing calorie intake leads to decreases in fat mass (Mettler et al, 2010).

3.9 There have been very few controlled research studies in elite athletes that show the effect of training and diet on body composition. This is potentially due to the small population of truly elite athletes available. However, there have been some case studies which show weight loss of 0.9 kg per week in athletes in response to weight loss programmes (Morton et al, 2010).

3.10 Despite few controlled studies on the effects of training in elite athletes, there are a number of cross-sectional and longitudinal studies which may give some insight into the effects of training. Handsfield et al (2017) used MRI imaging to investigate local muscle mass differences in sprinters and non-sprinters. Those muscles which cross the knee and hip were 30% greater in size in trained sprinters versus untrained sprinters. These muscles are involved in the process of sprinting and, therefore, it is unsurprising that they are larger as a result.

3.11 Body composition can change over the competitive season. In many sports this will involve decreases in body fat, along with increases in muscle mass. In professional football over a season one elite club reported increases in fat free soft tissue from 55.3 kg to 56.7 kg and decreases in fat mass from 10.1 kg to 8.7 kg during pre-season training using DXA (Devlin et al, 2017), with similar findings found by other researchers (Milanese et al, 2015). There is some evidence that as team sports progress towards the end of their competitive season there is a decrease in lean mass (1.2 ± 1.4 kg) and an increase in fat mass (0.6 ± 1.1 kg) among the players (Harley et al, 2011). In contrast, endurance athletes will generally get leaner as their competitive season progresses towards a peak performance, such as the Olympic Games (Haakonssen et al, 2016).

3.12 There can be significant changes in body composition as athletes mature during their careers. Analysis of body composition using DXA in a Premier League football club between the under 18 team, the under 21 team and the first team showed that there were no significant differences in fat mass between the age groups. However, there were significant increases in muscle mass as players mature, increasing from 60.6 ± 6.3 kg at U15 level through to 64.6 ± 6.5 kg at U21 level and 66.9 ± 7.1 kg for the first team (Milsom et al, 2015).

Benefits from body composition assessment for individuals, teams and society

3.13 Body composition is known to affect sporting performance, but at the present time, there is little evidence to show whether measurement of body composition for athletes could influence their performance. As sports become more competitive, there is a drive to take every step possible to maximise performance. Sports medicine has made tremendous strides over the last few decades, and as performance analysis intensifies there is a perceived need to obtain more information on athletes' body structures and their potential. Analysis of body composition is just one component that feeds into the equation, but it could be a key one. As athletes prepare with different training regimes and diets, their bodies adapt and the composition of their body tissues changes. An effective tool to measure these changes could enable athletes and their trainers to gain a better understanding of the effects that occur and how these are influenced by training and diet. This could be particularly important for monitoring changes in modern athletes aiming to achieve peak performance at specific events, such as the Olympic Games. If individuals or teams employ methods that provide information on incremental changes, it could give them the competitive edge required to win. Attempts to achieve the ideal body composition through specially designed protein and calorie intakes linked with training programmes without the appropriate monitoring tools might result in poor body weight management and could be a greater risk to the health of the individuals involved.

3.14 Other sportspersons, such as boxers who are required to be able to perform in particular weight categories, require information on body composition to confirm whether decisions on their classification are correct and realistic. Professional footballers and other team sportspersons that are required to maintain performance throughout long and arduous sporting seasons may undergo gradual changes in body composition and monitoring of these changes may be useful in maintaining performance levels and physical health.

3.15 DXA is one of the techniques available for the assessment of body composition and has practical advantages over other laboratory-based techniques. Measurements can be conducted reasonably rapidly and DXA can provide regional estimates of body composition. Moreover, it has the potential to be used for wheelchair athletes for whom other techniques may not be viable (see Chapter 4). If the assessment of body composition by DXA is deemed to be a justified practice, it may aid the understanding of the influence of body composition on sporting performance, as well as helping to avoid some of the risks to the health of the athlete from arduous training programmes. There is scarce information available from such practices at the present time due to the limited number of studies reported in the literature. It is impossible to draw definitive conclusions about the value that can be derived from assessments of body composition, although there are clear potential benefits. Therefore, if the practice were to be justified, it would be important for results to be analysed carefully and collated. Increasing the knowledge base would provide better assessment of benefits (and harm, if any) and enable development and improvement in the methodology, analysis and application for the future.

3.16 If assessment of body composition could aid an improvement of performance, then this can benefit the well-being of the individual sportsmen and sportswomen and the morale of the team. The winning of medals and trophies can motivate and inspire young sportsmen and sports women and can have life-changing impacts on elite athletes. Such achievements will raise the spirits of team supporters and so can provide tangible benefit to larger groups of individuals. Whether the potential benefits from the use of DXA assessments are worth considering in achieving this goal will depend on the associated risks. Controls are needed to keep any radiation exposure within pre-determined limits and ensure that repeated regular exposures that would give little additional benefit are not permitted.

Chapter 4: Radiological and other methods for assessment of body composition

Body composition assessment

4.1 The human body consists of a range of tissues with varying properties. To describe and measure these properties, some components with similar properties are grouped together. The components used may depend upon the outcome of interest. When fat content is the primary concern, the body may be described as a two-component model: fat mass (FM) and fat-free mass (FFM): all other mass (consisting largely of mineral, protein or water) (Wang et al, 1992). By measuring a property that differentiates between fat mass and fat-free mass, it is possible to estimate the relative proportions of these two compartments. For instance, the FFM has greater density than FM. Body composition can be assessed using laboratory-based techniques that measure such a property. For instance, assessment of body density by hydrostatic weighing (HW) or air displacement plethysmography (ADP) can be used to estimate FM and FFM by making assumptions about the densities of these two components. Deuterium dilution (D_2O) can be used to estimate total body water content and by making assumptions about the hydration of the components it is possible to estimate FM and FFM (Lee and Gallagher, 2008). DXA assumes that the relative attenuation of two X-ray beams of different energy is related to the proportions of bone and soft tissue (in pixels containing bone) and to the proportions of fat and lean soft tissue (in non-bone pixels) (Pietrobelli et al, 1996). However, this assumes a constant composition of these components, when they can vary within, and between individuals. The FFM includes tissues as disparate as bone and water. Their properties and proportion in the FFM can differ, affecting the properties of the FFM overall. In athletes in particular, differences in the proportions (e.g. greater bone or muscle mass) or properties of body compartments may affect the accuracy of measurements.

4.2 Multi-component models involve combining measurements using several techniques, allowing the estimation of further properties, such as bone mass and water content, as well as body density in the four component (4C) model (Pietrobelli et al, 2001). Using these models reduces the errors associated with variations in these components, although there is the potential for cumulative technical error.

4.3 Often there is a need to conduct body composition measurement in a setting where there may not be access to, or resource for, these relatively expensive laboratory-based techniques. Many field-based techniques use a “doubly indirect” approach, which involves measuring a parameter that varies with body composition and generating a prediction equation to estimate the value obtained from one of the laboratory-based methods above. Such techniques include anthropometric measurements or assessment of skinfold thicknesses (SKF), bioelectrical impedance (BIA) and ultrasound.

Accuracy of DXA

4.4 Assessment of the accuracy of a body composition technique requires a criterion measure to compare against. Direct assessment of human body composition can only be achieved by cadaver analysis. As such, multi-component models are often employed as criterion measures, with the optimum criterion measure in relatively widespread use being the 4C model. Evaluation of body composition techniques is most often analysed using methods proposed by Bland and Altman (1986), where the difference between the techniques is calculated (the bias). The mean bias (= accuracy) will indicate the magnitude of any consistent over- or under- estimation in the average for a group, whilst the error (= precision) or limits of agreement (~2 standard deviations (SDs) of bias) will reflect the extent of errors expected in the majority of observations in individuals. For instance, if the bias is -2% and the error 4%, this indicates that the technique underestimates by 2% on average, but there may be underestimation of up to 6% in some people and overestimation by up to 2% in others, based on a normal distribution with 95% confidence.

Table 4.1: Accuracy of DXA and other body composition techniques for assessing percent body fat relative to 5- or 4-C models.

Study	Population	DXA scanner make and model	Mean bias%	Error% (2SDs of bias)
Arngrimsson et al (2000)	10 male runners	Hologic QDR 1000W	DXA -2.9* HW +1.1 D_2O +1.4*	DXA 3.2 HW 4.2 D_2O 3.4
Arngrimsson et al (2000)	10 female runners	Hologic QDR 1000W	DXA -4.0* HW -0.1 D_2O +1.2*	DXA 6.0 HW 5.0 D_2O 5.4
van Marken Lichtenbelt et al (2004)	27 male bodybuilders	Lunar DPX-L	DXA +0.9 HW -0.1 D_2O +0.5 SKF +0.2 BMI +5.3*	DXA 5.5 HW 2.7 D_2O 3.4 SKF 7.9 BMI 6.6
Moon et al (2009)	29 female volleyball, softball or track and field athletes	Lunar Prodigy Advance	DXA -3.7* HW -0.0 ADP -0.8	DXA 6.4 HW 4.6 ADP 5.9
Santos et al (2010)	27 male judo athletes	Hologic QDR4500A	DXA +2.9-+3.7*	DXA 5.1

*Percent fat is significantly different from 4- or 5- C model estimations.

4.5 Mean percent values in groups of athletes have varied between 4% body fat below and 3% body fat above the mean estimated from a 4C model (Table 4.1; Toombs et al (2012)). On top of this consistent bias, there is an additional error of up to ~3-6% fat in individuals. The bias and error were greater for DXA than for other laboratory-based techniques (HW and D_2O) (Table 4.1), although error was greater for skinfold thicknesses. 4C estimations are not independent observations, but are based on measurements by HW, D_2O and DXA. As DXA is used just to measure bone mineral, which makes up a relatively small proportion of body mass, the DXA contributes relatively little variance to the 4C estimate, whilst HW and D_2O measurements contribute more. This means that these comparisons may favour HW and D_2O and do not provide evidence that DXA is more or less accurate than these other laboratory-based techniques.

4.6 The accuracy of body composition by DXA may alter according to the technology used and so may vary between different scanner makes and models (Toombs et al, 2012) and between software versions that use different algorithms. There may be variability in the extent to which beam hardening or magnification associated with fan beam technologies affect the findings (Pietrobelli et al, 1996). This means that it is necessary to evaluate the accuracy for each scanner, but there is limited information on the accuracies of some models.

Reliability of DXA

4.7 The reliability or precision error of DXA is usually described as the standard deviation (SD) of repeated measurements: ideally the root-mean-square SD (Gluer et al, 1995; Baim et al, 2008). This statistic may also be expressed in percentage terms as coefficient of variation (CV) (Gluer et al, 1995; Baim et al, 2008), which can be used to estimate the least significant change (LSC), calculated as 2.77 times the SD or CV. This reflects a sufficiently large change that it is unlikely to be explicable by precision error, or the smallest change that could be accepted as genuine change rather than precision error in an individual.

4.8 Better reproducibility has been reported in newer (e.g. narrow angle fan beam GELunar iDXA) than older models of DXA scanner in non-athlete groups. For instance, the CV for percent body fat given by the GE Lunar iDXA was 0.4-1.0% compared to 1.0-2.0% fat by the Lunar Prodigy (Toombs et al, 2012; Kaminsky et al, 2014). In team sport athletes, the CV for percent body fat was better for the Lunar Prodigy than the older DPX-IQ device (CV 2.5 and 5.9% fat respectively (Bilsborough et al, 2014)).

4.9 Studies in athletic populations using recent scanner models allow estimation of the LSC that may be expected based upon precision error alone. Relative precision error seems greater in regional measures with low tissue masses. For example, CVs were up to 8% for arm fat in male athletes compared to <2% for total body, leg and trunk (Buehring et al, 2014), although given the low arm fat content in male athletes, the seemingly large arm fat CV of 8% equated to just 22g of fat. In absolute terms, the LSC is well within 1 kg for total body FM or FFM (Table 4.2). The LSC for arm FM is around 0.1-0.2 kg (Buehring et al, 2014; Barlow et al, 2015); whilst that for arm FFM is 0.2-0.4 kg. LSCs for the leg and trunk are slightly larger in absolute terms (leg FM 0.2-0.4 kg FFM 0.4-1.0 kg; trunk FM 0.3-0.8 kg, FFM 0.5-1.1 kg). As such, changes to total body or regional FM or FFM of 1.1 kg or more could be identified as genuine change, so DXA may theoretically detect seasonal changes in athletes that are greater than this.

Table 4.2 Least significant change of total and regional body composition by DXA.

Study	Participants	LSC total body (kg)	LSC leg (kg)	LSC Arm (kg)	LSC trunk (kg)	Scanner make & model
Buehring et al (2014)	30 men (hockey, basketball & wrestling)	FM 0.46 FFM 0.57	FM 0.13-0.20; FFM 0.36-0.46	FM 0.10-0.13; FFM 0.15-0.21	FM 0.41 FFM 0.73	GE Lunar iDXA
Buehring et al (2014)	30 women (hockey, basketball & golf)	FM 0.32 FFM 0.38	FM 0.31-0.39; FFM 0.47-0.48	FM 0.09-0.10; FFM 0.15-0.16	FM 0.30 FFM 0.47	GE Lunar iDXA
Barlow et al (2015)	45 elite male rugby players	FM 0.77 FFM 0.89	FM 0.40; FFM 1.02	FM 0.17; FFM 0.38	FM 0.83 FFM 1.11	GE Lunar iDXA

4.10 Most studies of reliability are conducted with measurements repeated on the same day, which may reduce technical variation as well as eliminating the influence of day-to-day biological variation such as fluctuations in hydration status. The long-term precision (with measurements repeated on different days) may be a better indicator of precision error and precision errors for bone mineral measures by DXA are greater for assessments performed on different days (Leslie, 2008). Although most studies have only reported precision with repeat scans conducted on the same day, the long-term root-mean-square SD using a Hologic scanner was reported to be 0.59% body fat, yielding an LSC of 1.6% body fat (Powers et al, 2015).

Accuracy of DXA for assessing body composition change

4.11 Given the reasonably good precision of DXA, it may be expected to be a useful tool for assessing body composition change in athletes and this has been examined in a few of studies that used a 4C model as the criterion technique. Whilst mean changes in percent body fat were similar according to DXA and the 4C model in judo athletes (Santos et al, 2010) and bodybuilders during gain in FFM (van Marken Lichtenbelt et al, 2004), differences (assessed from 2 SDs of bias) of up to ~4-5% body fat (~3 kg FFM) were determined in both studies (Table 4.3). Other laboratory-based methods and skinfold thickness measurements demonstrated smaller errors and so may provide better accuracy for assessing change. However, these studies have not evaluated the accuracy of the most recent scanner models.

Table 4.3 Accuracy of DXA for assessing body composition changes relative to 4C model

Study	Population	DXA scanner	Mean bias	Error (2SD)
van Marken Lichtenbelt et al (2004)	27 male bodybuilders	Lunar DPX-L	DXA -0.2 HW -0.1 D_2O +0.4 SKF +0.3 BMI +2.6* BIA +1.5	DXA 3.8 HW 2.4 D_2O 3.1 SKF 3.0 BMI 3.7 BIA 6.3
Santos et al (2010)	27 elite male judo athletes	Hologic QDR 4500A	DXA 0.8	DXA 4.5

Factors influencing accuracy and reliability

4.12 Soft tissue hydration may affect fat estimation by DXA; although this effect may be smaller than for some other techniques, with hydration changes of 1-5% reported to affect body fat estimates by <1% (Pietrobelli et al, 1998). However, small changes resulting from variations in hydration and/or fluid distribution will increase the precision error. In athletes, exercising prior to measurement increased the error by around 10% (Nana et al, 2013). Larger increases in precision error were produced when conducting measurements at different times of day; this was further increased when food and drink were consumed prior to measurement (Nana et al, 2012). Recommendations to ensure that measurements for detecting changes in body composition are as reliable as possible are that assessments should be conducted 1) in minimal clothing (e.g. underwear); 2) in the morning; 3) in a fasted state; 4) without prior exercise; 5) hydration status should be confirmed (e.g. by measuring urine specific gravity) and 6) the bladder should be voided before measurement. From a technical point of view, regular quality control and assurance procedures of both equipment and techniques should be conducted and standardised positioning protocols used (Nana et al, 2015).

Use of DXA in wheelchair sports

4.13 In wheelchair athletes, regional tissue loss or atrophy may invalidate the assumptions made in many other body composition techniques. As DXA allows regional assessment it may theoretically offer greater accuracy, although this has not been evaluated relative to a multi-component model. It is hard to validate the accuracy of the technique when the methods to which it may be compared may be less effective in this population group. Precision has been assessed, with the LSC in wheelchair basketball players (1 kg for FM, 1.1 kg for FFM) being similar to that in able bodied athletes (Keil et al, 2016). Given the limited viability of other techniques, DXA may be particularly important for this population group.

Advantages and disadvantages of DXA compared to alternative techniques

4.14 As discussed previously, studies have reported that other laboratory-based techniques have accuracy as good as, or better than, DXA. However, they do not provide regional measures of body composition and have some practical disadvantages. Obtaining accurate measurements with HW involves submersion in water, combined with lung volume measurements estimated by rebreathing procedures. Instructions can be complex and the procedure may be unpleasant for those who do not like submerging in water or who suffer from claustrophobia. HW facilities are not widely available. ADP can be assessed by a commercially available device, but involves sitting in a sealed pod (so it may again be unpleasant for those who are claustrophobic) and accuracy may be affected by presence of facial or body hair. D_2O requires access to mass spectrometry facilities for sample analysis and may be particularly affected by changes in hydration.

4.15 Field techniques may offer less accurate measures, but have the practical advantages of being cheap and portable. However, BIA may be affected by changes in hydration and SKF is very dependent upon operator skill.

4.16 One practical advantage of DXA is that it can provide regional estimates of body composition. Measurements can be conducted reasonably rapidly (~5-25 minutes depending upon scanner type and body size) and are not demanding on the participant. Colour coded DXA scan images may be helpful visual feedback to target regional hypertrophy or reinforce behaviour change. Disadvantages are that the equipment is expensive and requires a trained operator, and the scanner bed may be too small for some athletes who are particularly tall or broad (Nana et al, 2015).

Conclusions

4.17 Studies in athletes have not demonstrated that DXA provides more accurate assessment of body composition than alternative laboratory-based methods such as hydrostatic weighing or deuterium dilution. However, the other laboratory-based techniques require more specialised equipment and a greater degree of expertise and skill to perform, and are more demanding upon the participant, so DXA offers practical advantages.

4.18 The reliability of newer DXA scanners appears to be good enough to allow detection of changes in FM or FFM of the order of 1 kg, which may be sufficient to assess seasonal variation in athletes. However, some older models may not be able to achieve this level of accuracy and may not be suitable for the application. A key advantage is that DXA allows regional measurements. There is insufficient information currently on the accuracy of newest scanner models and software versions, validated against robust methods such as 4C models.

4.19 Studies evaluating and comparing the accuracy of various techniques for assessing changes in body composition suggest that other laboratory-based techniques, and even skinfold thickness measurements, are at least as accurate. However, such studies have not compared the newer scanner models that are reported to have greater reliability and so could offer more precise monitoring of body composition change. Furthermore, earlier DXA studies did not always standardise factors such as time of day, clothing and prior exercise and fasting that could contribute to errors. Evidence suggests that these factors must be controlled in order to provide accurate and reproducible data.

4.20 Overall, DXA does not have better accuracy or reliability than other techniques; its main advantages are its ease of use for the participant and its ability to produce regional measures of body composition. Earlier studies did not use standardised measurement conditions and newer scanner models and software versions, coupled with standard measurement conditions, may have better accuracy.

Chapter 5: Radiation doses from DXA scans

Harmful effects of radiation

5.1 Ionising radiation interacts with cells and tissues through a variety of mechanisms. In addition to the direct damage from the interaction with DNA and other biological molecules, there is evidence that changes may also occur in nearby cells. Stable mutations can provide proliferative advantage and ultimately result in cancer, but the only way of quantifying potential risks is through studies of effects on human populations.

5.2 Epidemiological studies of populations exposed to whole-body absorbed doses over 100 mGy (10^5 μGy), predominantly the Japanese survivors exposed at the time of the detonation of the A-bombs in Hiroshima and Nagasaki, have shown statistically significant excesses of radiation-induced diseases, principally cancer. Moreover, the risk of cancer is greater for children and the unborn child. Risks at very low doses are impossible to measure using epidemiological studies. Consequently risks are inferred by back extrapolation assuming that a linear non-threshold (LNT) dose–response relationship applies at lower doses and dose rates. In the context of DXA scanning, the doses involved are over 1000 times less than those to populations considered in any epidemiological studies that have provided evidence of an increased risk of cancer, and consequently, any potential risks must be exceedingly small.

Quantities for assessing radiation dose

5.3 Evaluation of radiation dose levels from DXA equipment is difficult because the actual radiation doses are so low. The International Commission on Radiological Protection (ICRP) has developed the *effective dose*, a protection quantity with the unit ‘sievert, Sv’, to allow comparisons of radiation doses from different sources and of different types in terms of health detriment. An effective dose of 1 Sv equates to a mean whole body dose of 1 Gy in terms of detriment for photon X-radiation. Effective dose enables comparisons between exposures giving different distributions of absorbed energy in organs of the body in terms of the possible effect on health (ICRP, 2007). It involves the application of tissue weighting factors to the doses received by the irradiated organs approximately reflecting their relative sensitivities to stochastic effects. The factors are based substantially on risks of cancer incidence derived from epidemiological data from the Life Span Study of the Japanese A-bomb survivors, for whom the organ and effective doses received were factors of at least 10^3 higher than the microsievert doses estimated for DXA scans. Inferred risks of cancer at very low doses are uncertain. However, it is not necessary for the purposes of understanding and evaluating possible risk to postulate that an LNT dose-response relationship continues down to microsievert levels. The general UK population is exposed to external photon radiation from natural background of the order of 1 mSv (1,000 µSv) per year and so it is increments of dose (and risk) above this level that require evaluation. It is reasonable, therefore, for present purposes, to assume that the risk associated with an incremental increase in dose associated with DXA scans can be inferred from the estimated effective dose, recognising that this is an inferred value of possible risk at very low levels of radiation exposure.

5.4 Effective dose is a radiation protection quantity that is derived from assessments of the absorbed doses to exposed organs. This can either be done through Monte Carlo simulation of the passage of X-ray photons through the tissues or measurements of organ doses using thermoluminescent or other dosimeters placed inside anthropomorphic phantoms. The effective dose relates to the entrance surface dose, the energies of photons in the X-ray beam (determined by the tube potential (kV) and metal filters placed in the beam), and the size of the area on the body that is scanned. The entrance surface dose is a measure of the dose to the surface of the skin irradiated directly during a DXA scan, so values of this and approximate values of the effective dose are helpful in assessing the level of exposure.

Dose levels from whole body and local DXA scans

5.5 There have been a number of studies to determine radiation dose levels from the use of DXA in bone densitometry applications. These studies provide the evidence for estimating effective doses likely to be received from DXA body composition measurements linked to assessment of sporting performance.

5.6 Dose data for DXA equipment are limited, but do confirm that the radiation doses from the current models of DXA scanners are very low. As indicated in Chapter 2, the radiation can be delivered by a thin beam of X-rays in one of two ways: either by i) a 'pencil beam' or ii) a 'fan beam' system. For a standard DXA spine and hip assessment, the effective dose given by a 'pencil beam' system is typically less than 1 µSv (Kalender, 1992; Bezakova et al, 1997; Njeh et al, 1997; UNSCEAR, 2000), but pencil beam systems are now used little, if at all. Effective doses for 'fan beam' systems can vary between 2 and 75 µSv[1] (Table 5.1), but effective doses for whole body scans with fan beam systems from studies performed in the last 20 years are within the range of 2-10 µSv. This would suggest that a single DXA scan would increase the lifetime risk of cancer incidence by less than 1 in 1 million, on the basis of an LNT extrapolation of risk from high dose levels.

5.7 Fan beam DXA scanners give entrance surface doses up to about 900 µGy, although lower values are used for scans of the whole body. The setting of modes for spine and hip scans have a major influence on the radiation dose received. Doses for the spine examination in the study by Blake et al (2006) in Table 5.1 were for the "Array" mode that delivered the highest dose, but two other options were available; a "Fast" scan mode, which delivered about half the dose of the Array mode and an "Express" mode, which delivered one third of the dose.

5.8 For the purpose of bone densitometry, scans are commonly performed on the spine or hip, but scans to assess body composition are likely to be either of the whole body or the limbs. The whole body scans that are performed for the purpose of assessing bone density usually employ exposure factors that give lower entrance surface doses. Table 5.1 shows results from bone densitometry studies performed with fan beam DXA systems to give some indicative values of effective dose and entrance surface dose from fan beam systems. The results indicate that

[1] https://www.fsem.ac.uk/position_statement/dexa-use-in-sports-medicine/

the effective dose for an adult whole body scan can be derived by multiplying the entrance surface dose by a constant equal to between 0.25 and 0.32.

Table 5.1: Effective doses and entrance surface doses (ESDs) from studies with fan beam DXA systems.

Area scanned	DXA unit	Effective dose Adult (μSv)	Effective dose 15 y old (μSv)	ESD (μGy)	Reference
Whole body	Hologic Discovery - A	4	4	13.0	Blake et al (2006)
Whole body	Hologic Discovery - W	8	8	26.1	Blake et al (2006)
Spine	Hologic Discovery - A QDR4500	13	15	352	Blake et al (2006)
Whole body	Hologic QDR4500A	2	2	7.6	Thomas et al (2005)
AP spine	Hologic QDR4500A	2	2	131	Thomas et al (2005)
AP spine	DMS Lexxos	8.4		90	Boudousq et al (2003)
Whole body	Lunar Expert XL	75			Steel et al (1998)
AP spine	Lunar Expert XL	56			Steel et al (1998)
PA spine	Lunar Expert	75		895	Njeh et al (1996)
Whole body	Hologic QDR 2000	3		11	Lewis et al (1994)
AP spine	Hologic QDR 2000	2		271	Lewis et al (1994)

5.9 The study by Blake et al also included data on radiation doses to children from paediatric DXA examinations (Blake et al, 2006). Children receiving DXA scans using the same settings as those for adults will receive a higher dose than adults because the layers of overlying tissue are thinner and so do not attenuate the X-ray beam to the same extent and offer less protection to the internal organs. These differences are more marked for children of 5 years and 10 years than for 15 year olds included in Table 5.1. For scans of localised parts of the body, the size of the scanned region will influence the effective dose and this should be adjusted according to the size of the individual and the area to be scanned. Fan beam DXA systems tend to have a fixed beam width determined by the collimator and the scan length can be adjusted to the length of the individual being scanned. Newer DXA scanners have shorter scan times and this helps to reduce movement artefacts.

5.10 The dose results reported in Table 5.1 relate to measurement of bone mineral density and, therefore, are only indicative of dose levels for the evaluation of body composition. Moreover, the dose levels cover a range of more than a factor of ten. The scans with dose levels at the upper end are for the spine and are used to assess bone density. However, the need for examinations that deliver dose levels at the upper end of the range should be considered carefully. More data on scan parameters and dose are required relating to the exposure levels and area of the body scanned to establish typical dose levels for evaluation of body composition.

This should include assessment of entrance surface dose and, if available, effective dose.

5.11 The occupational dose to DXA scan operators arises from the scatter of X-ray photons from the beam as it passes through the body of the individual being scanned (Blake et al, 1996; Njeh et al, 1996; Patel et al, 1996; Steel et al, 1998; Boudousq et al, 2003). Dose levels are low, but exposure would be determined by the numbers of scans performed and the design of the scanning room. The advice of a radiation protection adviser must be sought in determining appropriate protection measures.

Radiation dose and health detriment from DXA

5.12 Dose levels from DXA scans are very small (Table 5.1). A useful way of putting these doses into context is to compare them in terms of the length of time a person must be exposed to natural background radiation to receive the same dose. The average cumulative effective dose from all natural sources of radiation (internal and external background radiation) is about 2,300 μSv per year, equivalent to 6 μSv a day[2], so the dose from a whole body DXA scan will be roughly equivalent to the dose received from background radiation in a day[3]. It is also similar to the effective dose of 5 μSv that an average person in the UK receives from natural radioactivity in food consumed each week (Oatway et al, 2016).

5.13 The dose can also be compared with that received from cosmic rays during plane flights. A transatlantic flight would typically involve an effective dose of 60 μSv, while the range of average effective doses received by aircraft crew during their work is 1,200 to 5,000 μSv per year, with maximum values of 6,000 to 7,000 μSv (ICRP, 2016).

5.14 Another way of putting doses from DXA scans into perspective is to compare them to those from conventional radiographic X-ray examinations. In the UK, the typical effective dose from a chest postero-anterior radiograph, which is the radiation examination of the trunk with the lowest dose, is 14 μSv, while that from a lumbar spine radiographic examination is 400 μSv and CT examinations of the trunk deliver effective doses between 6,000 and 10,000 μSv (Wall et al, 2011).

5.15 Since the risks from a DXA scan are very small, it would seem reasonable to justify the practice, if there is a potential benefit to the scanned individual that may outweigh the risk. However, an individual could be subject to multiple exposures as part of a training programme, and if they continue to participate as an athlete, sportsman or sportswoman, regular exposures could be made over many years. In addition, sportsmen and sportswomen are towards the younger end of the age spectrum, and many may be under 25 years of age, and radiation risks are generally greater after exposure at younger ages. Therefore, limits should be placed on the time interval between scans and the number of scans performed each year.

[2]https://www.phe-protectionservices.org.uk/radiationandyou/
[3]https://www.iaea.org/resources/rpop/health-professionals/other-specialities-and-imaging-modalities/dxa-bone-mineral-densitometry/patients

Restrictions on the use of DXA linked to assessment of sporting performance

5.16 A routine DXA scan will deliver a very small radiation dose to the individual being scanned. The dose to the skin is easily measured, and from this estimates can be made of doses to underlying tissues and so the effective dose calculated. When DXA examinations are undertaken sufficient records should be kept to allow assessments to be made of the doses received.

5.17 For medical exposures, there are no upper limits on the number of scans that can be performed, although they will not be justified if they will not influence the management of the patient. There are diagnostic reference levels that provide guidance on safe practice (ICRP, 2017). These are quoted in terms of measurable dose quantities and are based on surveys of patient dose levels made by medical physics departments throughout the UK. The gathering of further information from research studies may inform whether a similar system is applicable to the use of DXA or any other radiation-based technique for making assessments linked to sporting performance.

5.18 The radiation exposure for every individual and each scan could be justified in terms of the risk and benefit by a registered health care professional appropriately entitled as an IR(ME)R practitioner by the employer responsible for the exposure (see Chapter 6 and Appendix B). Good radiological practice should always be followed. Alternative methods for determining body composition should be carefully considered.

5.19 Due to the low radiation dosage, limited repeat measurements on the same individual might be permitted. However, if repeat scans were required, DXA will not be sensitive to the small changes in body composition seen over short time periods. The justification process should show that the potential benefit outweighs the potential risks for the total number of scans required.

5.20 Increased scrutiny should be given to exposures involving sportsmen and sportswomen at the younger end of the age spectrum, since radiation risks may be greater. Particular attention should be given to ensuring the purpose of the programme is justified and appropriate adjustments should be made to ensure scanning protocols are optimised for body size.

Chapter 6: Principles and usage of DXA for non-medical imaging exposures

The ALARA Principle

6.1 The radiation doses from DXA scan are extremely small. Nevertheless, any radiation exposure should be kept as low as reasonably achievable (ALARA), taking account of social and economic factors. Good practice dictates that appropriate measures are taken to justify any exposure that is made, and that equipment performance is optimised. To achieve this, DXA equipment scanners should be subject to a regular maintenance programme and exposure factors chosen to minimize the dose to the exposed individual, while providing the information on body composition required.

Definition and justification of non-medical and medical exposures

6.2 Within the EU, medical exposures of patients or asymptomatic individuals are defined in the Basic Safety Standard Directive (BSSD) as exposures incurred by patients or asymptomatic individuals carried out as part of their own medical diagnosis or treatment and by volunteers in medical or biomedical research.

6.3 Types of exposure for athletes that would be treated as medical exposures would include:

- Diagnosis of potential or actual injury including long term health conditions
- Assessment of bone health
- Body composition to determine the health of the individual e.g. the detection or avoidance of the RED-S.

6.4 Non-medical exposures for sports performance would not meet these requirements as the primary reason for carrying them out would not bring a health benefit to the individual being exposed. Examples of these exposures would include

- Body composition measurements as part of training programmes or to determine appropriate weight category for combat type sports.
- As part of an assessment of an individual’s biological age.

6.5 IR(ME)R 2017 is part of the implementation of the BSSD (Euratom, 2014), and covers both medical exposures and exposures involving non-medical imaging using medical radiological equipment. The definition of a non-medical imaging exposure is “any deliberate exposure of humans for imaging purposes where the primary intention of the exposure is not to bring a health benefit to the individual being exposed”. The principles of justification, including non-medical human imaging, have been discussed by the International Atomic Energy Agency (IAEA, 2014). The principle of justification is that practices must produce a positive net benefit to the exposed individuals, or to society. In relation to the use of imaging in sport which is not for diagnostic purposes they clarify the need for such practices to be explicitly justified. They also identify a number of potential applications, including selection of athletes for competitions, support for decisions on training and nutrition, and as a precautionary tool to identify conditions that would lead to increased risk for the individual involved. They note that such uses of imaging are important but require guidance to prevent misuse.

6.6 BSSD Article 55.1 (Euratom, 2014) requires that any new type of practice involving medical exposure shall show a sufficient net benefit, to the individual and to society, against the individual detriment that the exposure might cause. When potential benefits to the individual have not yet been demonstrated definitively, any application of the practice should be limited to controlled situations in which exposures are made in accordance with agreed protocols. This facilitates detailed assessments of relevant evidence, in order that the results of measurements can be evaluated and evidence accumulated.

Benefits, limitations and risks of DXA

6.7 Each procedure using ionising radiation will have potential benefits and risks to the individual. These have been considered for DXA, together with any limitations associated with the technique.

Benefits of DXA:

- A DXA scan is a simple, quick and non-invasive procedure.
- The amount of radiation used is extremely small, and the effective dose (2-10 μSv for a whole body scan[4]) is typically less than half of the dose from a standard chest X-ray (14 μSv (Oatway et al, 2016)), and similar to a day's exposure to natural background radiation.
- DXA is one of several techniques that can be used for estimation of composition of the whole body. A scan can be conducted reasonably rapidly, whereas other techniques involve procedures that are more complex in practical terms and are not widely available.
- DXA can provide regional estimates of body composition, which are not possible with other techniques. It is also straightforward to use DXA, including for regional assessments, in situations where this would otherwise be difficult or impossible, such as for wheelchair users or for people with medical implants. Assessments of whole body composition using other techniques may be invalidated because of regional tissue loss or atrophy in wheelchair athletes.
- DXA may benefit weight management for athletes as it can provide an assessment of lean body mass and fat mass, giving the athlete and his/her support team information with regard to weight loss possibilities. A risk of not allowing DXA to be used could be an increase in weight management practices that may have adverse effects on athletes' health.
- The use of DXA may have benefits to society as a whole. If assessment of body composition can aid in improvement of performance then this can benefit the well-being of the individual sportsmen and sportswomen and the morale of the team. The winning of medals and trophies can motivate and inspire young sportsmen and can have life changing impacts on elite athletes. Such achievements will raise the

[4] Effective doses for whole body scans with fan beam systems from studies performed in the last 15 years (see Table 5.1).

spirits of the team supporters and so can provide tangible benefit to larger groups of individuals.

Limitations of DXA:

- DXA is not more accurate than other laboratory-based techniques for assessing whole body composition, such as ADP, HW and D_2O.
- Changes in hydration and fluid distribution will affect the accuracy of the technique.
- DXA is only able to measure changes in body composition greater than about 1 kg and this may limit its value for some applications. Moreover, it is no more accurate than any of the other techniques, namely skinfold measurement, HW and D_2O.
- The value in assessing body composition linked to sporting performance has not been proven.

Risks from DXA:

- An individual could be subject to multiple exposures, as part of a training programme, and if they continue to participate as an athlete, sportsman or sportswoman, regular exposures could be made over many years. In addition, sportsmen and sportswomen are towards the younger end of the age spectrum, so that the possible risks from radiation exposure may be greater than for the population as a whole. If an athlete were to have six exposures per year over an active period of 25 years, this is likely to amount to a cumulative dose of 1-2 mSv, assuming the dose per scan is around 10 μSv. The estimated risk from this cumulative dose would be very low. This assessment depends on the dose level used, and evaluation of dose will be important in the early stages of application, if the practice were to be justified
- There are potential risks, especially for younger individuals, other than radiation which should be considered. Anyone could develop an obsession with body image and could seek to have DXA scans to verify muscular development. Adolescents may be especially susceptible in this regard. Children could be influenced into participation by their desire to achieve strict training regimes or be drawn into such programmes through peer pressure. Thus there may be particular risks for younger persons, if there are no controls on the procedure.

Alternative techniques for assessing body composition not using ionising radiation

6.8 HW, ADP and D_2O offer accuracy as good as, or better than, DXA for assessing whole body composition, but do not provide regional measurements.

6.9 HW and ADP involve complicated rebreathing procedures and may be unpleasant for those that do not like confined spaces or submerging the face in water. D_2O requires access to mass spectrometry facilities and is affected by changes in hydration.

6.10 BIA is cheap and portable, but may offer lower accuracy and be affected by hydration.

6.11 Skinfold measurement is less accurate for absolute measurement of body composition and requires a highly trained practitioner. However, it is cheap, portable and may be as accurate as more demanding techniques for determining changes occurring in an individual between assessments (van Marken Lichtenbelt et al, 2004).

6.12 These methods for determining body composition should be carefully considered before deciding on the use of DXA. If it is changes during training or dietary regimes that are to be followed, techniques such as skinfold measurement may be appropriate.

Potential application to individuals who may be scanned

6.13 It would be appropriate for DXA scans in relation to the assessment of sporting performance to only be carried out as part of a recognised sports training programme. Such a programme would normally be designed by appropriately trained professionals, such as sports scientists or nutritionists, in consultation with a medical doctor. The use of DXA examinations could be planned in conjunction with a radiologist or other medical doctor with appropriate expertise in radiological imaging who could perform the role of the IR(ME)R practitioner.

6.14 Such a programme could include recommendations on training regime, diet or other aspects relevant to the assessment. It could include recommendations on how and when imaging should be performed, bearing in mind that changes in hydration, fluid distribution, timing of the examination, and other factors will affect the accuracy of DXA measurements of body composition.

6.15 A prior assessment of benefits and risks could be made before implementation of any programme. This could include the perceived objectives from the training or dietary programme and estimates of dose and risk for the full programme made by a medical physics expert (MPE) with relevant expertise. The employer could set a dose constraint within the scanning protocol based on advice from the MPE and this could form part of the justification process and be used in providing advice on risk to individual athletes.

6.16 The programme might include a statement of the minimum interval between repeat scans and the maximum number in the full programme. The frequency could take into account that DXA is only able to measure changes in body composition greater than about 1 kg in the fat or muscle component. It would be advisable for individuals only to be involved in one programme at any time.

6.17 Sufficient information relevant to the exposure requested could be included in the training programme to enable the IR(ME)R practitioner to decide whether the exposure(s) could be justified. Once such a justification process had been undertaken for a training programme, individuals might be referred onto the programme, within a formal structure that had been previously agreed. Subsequently, assessment and evaluation might be carried out using the same protocol and qualified operators could be identified to oversee the inclusion of individuals into the programme and supervise the sport training regimes.

6.18 National organisations with professional responsibilities for particular sports could perform useful roles in standardising training programmes involving DXA scans, and collation of DXA data and sporting performance results. This could contribute to the gathering of evidence on whether measurements of body composition can influence the sporting performance of athletes.

Limitation on numbers of scans

6.19 Repeated scans might be justified to detect changes in body composition and/or to monitor interventions. To do this, the frequency of scans might be chosen based on the magnitude of change that could be detected by DXA. As DXA can only detect changes in body composition of the order of one kg, scans could only usefully be repeated at intervals over which changes of this magnitude may be expected. For instance, to detect changes resulting from an intervention that might substantially influence body composition, scans should not be repeated using intervals less than six weeks, whilst to detect more gradual change a longer interval (e.g. competitive season) might be more appropriate. If a period of less than six weeks between scans is proposed, then this should require special justification. It may also be applicable to place a limit on the maximum number of scans that an individual could be given over a year. Given that an individual would only be likely to gain benefit from such scans during a period of the year when they were participating in an organised training or dietary programme, and this would be unlikely to continue throughout the entire year, it may be reasonable to limit the number of scans undertaken to six in a single calendar year, until more evidence about the accuracy of the technique becomes available. Particular care should be taken when considering programmes involving children under 16 years of age.

Controls for the safe and effective use of DXA linked to sport performance assessment

6.20 The system of justification and authorisation is regulated by IR(ME)R 2017. A summary of the processes that should be followed and the duty holders with responsibility for carrying these out is given in Appendix B.

Justification of individual DXA scans

6.21 All exposures to ionising radiation made in relation to assessments linked to sporting performance must be justified prior to the exposure being made. The IR(ME)R practitioner entitled by the employer will be responsible for justification of individual exposures, based on his/her knowledge of the hazard associated with the exposure and the anatomical / physiological information required, taking into account the efficacy, benefits and risk of alternative techniques having the same objective, but involving no or less exposure to ionising radiation (see Appendix B).

6.22 Medical devices marketed or sold in the EU must comply with COUNCIL DIRECTIVE 93/42/EEC[5] and be CE marked to ensure patient, user and others safety.

6.23 The physiological changes that occur during pregnancy mean that any results are likely to be of little value, so the exposure would not be justified. Therefore, exposures should not knowingly be performed on any individual who is pregnant.

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[5] http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31993L0042

However, because the risk to the foetus would be very low, no action would be required should the individual subsequently find out that they were pregnant.

6.24 It would be appropriate to provide an explanation of the procedure and seek consent from individuals being examined (see Appendix C). This should include an explanation of the estimated risk as required by IR(ME)R 2017.

Procedures for optimization and assessment of scanner dose levels

6.25 The optimisation process involves ensuring that doses arising from exposures are kept as low as reasonably achievable (ALARA principle). Optimisation relies on the competence and skill of the imaging professionals to affect the exposure in a manner that achieves an appropriate balance between obtaining of the necessary information and the radiation dose delivered to the individual examined.

6.26 At installation a requirement could be included for an evaluation of the imaging and dose performance of the equipment. This could include an evaluation of its suitability, including the accuracy for measurement of fat/muscle composition based on equipment specifications, and measurements of the entrance surface dose levels for different examinations. If estimates could be made of effective doses for scans that are likely to be performed, these could be used in subsequent risk assessments. Multiplication of the entrance surface dose by a factor of 0.3 could be used as an estimate of effective dose from a whole body scan (see paragraph 5.8), if more detailed information was not available.

6.27 The evaluation could be performed by, or under the supervision of, a MPE trained in diagnostic radiology physics. Quality assurance measurements on the equipment, as recommended by professional bodies in national guidelines, would be required under IR(ME)R 2017.

6.28 There is the potential that DXA could be used for other non-medical purposes, for example by nutritionists and beauticians. These applications are not considered in this report, but the justification of practices in these and other areas may need to be considered in the future. A process involving an expert review of the available evidence should be developed to help in the evaluation of whether such practices should be justified in the future.

Management of incidental findings detected during research imaging

6.29 An incidental finding (IF) may be defined as ‘a finding that has potentially significant health or reproductive importance about which the participant is unaware, which is discovered in the course of conducting research, but is unrelated to the purpose and aims of the study’. In an assessment of IF in imaging research, Orme et al defines it as an observation noted in the dictated radiology report that was not directly related to the aims of the respective research study as listed in the protocol title' (Parker, 2008; Orme et al, 2010). An example of a classification system of medical research IFs is provided in Table 6.1.

6.30 There is wide variability in the incidence of IFs during non-medical imaging examinations:

- Orme et al (2010) reported IF to vary between 4.2% (nuclear medicine) and 60.9% (abdominal / pelvic CT), with further medical action being required in 0 - 9.2% of cases.
- Siddiki et al (2008) described IFs in 15 - 89% of CT colonography examinations, with 1.3 - 19% requiring follow-up and treatment.
- A review of cardiac imaging studies conducted by Colletti (2008) detected non-cardiac IF in 8 - 81% of examinations and concluded that all available data should be evaluated and appropriate judgements applied to the possible course of treatment.

Table 6.1 Classification of IFs for medical imaging research in the USA adapted from Wolf et al (2008).

Category	Relevant IFs	Recommended Action
Strong Net Benefit	• information revealing a **condition likely to be life-threatening** • information revealing a **condition likely to be grave that can be avoided or ameliorated**	• **Disclose** to research participant as an IF, unless they elected not to know.
Possible Net Benefit	• information revealing a nonfatal condition that is likely to be grave or serious, but that cannot be avoided or ameliorated, when a research participant is likely to deem that information important	• **May disclose** to research participant as an IF, unless they elected not to know.
Unlikely Net Benefit	• information revealing a condition that is not likely to be of serious health or reproductive importance • information whose likely health or reproductive importance cannot be ascertained	• **Do not disclose** to research participant as an IF.

6.31 As described above, the majority of published studies that evaluate IF involve CT and MR imaging. There are a few published studies that evaluate IFs for DXA examinations. DXA is widely used for non-invasive assessment of bone integrity as it provides improved spatial resolution and high image quality.

6.32 Bazzocchi et al (2012) reviewed DXA examinations in their medical institution to determine incidental findings and their potential impact on patient healthcare. The authors focused on whether IFs were reported by radiologists and the subsequent potential impact of these findings. The authors retrospectively and randomly assessed 739 examinations from a new DXA unit. Of these 191 (25.8%) were whole body scans; 96 (13.0%) were vertebral fracture assessment; 231 (31.3%) were lumbar spine and 221 (29.9%) were assessment of femur. They reported IFs in 15.8% of DXA examinations; 14.5% in whole body scans relevant for body composition measurements.

6.33 The largest number of IFs (35%) were found in vertebral fracture assessments. Of the IFs in this study, 42.7% were verified by other imaging modalities and 98% of these were true findings. The abnormalities included biliary and urinary stones (4.8%), vascular calcifications (33.7%), other soft tissue calcifications (25.3%), vertebral abnormalities (14.5%), other bone abnormalities (12.1%) and morphovolumetric alterations or abnormal anatomical structures (9.6%).

6.34 In the UK the most appropriate consensus report, entitled "Management of Incidental Findings Detected During Research Imaging", was published by the Royal College of Radiologists in collaboration with a number of nationally recognised stakeholders (RCR, 2011). Although this guideline documentation is aimed at IFs in research studies specifically, it can be applied to findings in non-clinical (DXA) examinations. The relevant points with respect to the use of DXA in non-medical imaging are:

- IFs raise ethical and legal issues that are not explicitly addressed in guidelines. There is little consensus in the UK (or elsewhere) as to how the consequences of the use of imaging (in research) should be handled. Guidance from regulatory bodies is ambiguous.

- There is a lack of evidence on which to base practice regarding a number of issues concerning information provided to research participants. For example:
  - the balance of harm versus benefit in telling research participants about findings
  - false-positive rates
  - how often it might cause a serious problem if research participants were not told anything or were told about inconsequential findings
  - pick-up rate of radiographer/researcher versus specialist radiologist.

6.35 Both the UK Department of Health and the National Research Ethics Service (NRES) state that the research participant 'should be made aware of possible disadvantages and risks of taking part in research' and that 'the risks should be outlined, including the discovery of another condition of which they were unware' that 'might have medical or insurance implications' and what the arrangements would be for dealing with this.

6.36 The legal obligations to disclose findings and the associated liability may vary depending on whether the relationship between the researcher and the research participant is viewed as similar to that of a physician/patient or rather as one involving researcher/participant. However, in the UK, it is advisable that a policy of transparency and a reasonable standard of care is adopted. The information to be disclosed could be incorporated into the consent process for each participant.

6.37 It is important to remember that when considering a reasonable standard of care, the courts will take ordinary and common practice and the views of a responsible body of professionals into account.

6.38 In general, even when the research participant is told that the scan is not for medical purposes, the limited evidence available suggests that research participants associate medical imaging equipment with the process of diagnosis, which may raise the expectation that their images will be reviewed by a competent professional.

6.39 Similarly, limited available evidence suggests that many research participants, including those who are researchers themselves, expect that they will be told of any potential life-threatening abnormality that shows up on a research scan and that there will be some guidance as to what to do about it.

6.40 Existing ethics and regulatory guidance is not explicit about IFs and practise for interpreting, and managing any medical or other consequences of IFs varies widely across sites.

6.41 A framework to standardise understanding of the issues and options for management of imaging research to deal with IFs across institutes would be beneficial, but is currently not available.

6.42 The extent and scope of the researchers' duty of care to the research participants is not well defined or tested (in litigation), but a researcher is expected to exercise reasonable care towards their participants, including to feedback information on any IF of a treatable condition.

6.43 Research imaging is designed to address specific scientific questions. Its primary function, particularly in normal participants, is not as a diagnostic test for a clinical condition, nor as a screening test. Therefore, in general, there should be no expectation on the side of the participant or obligation on the side of the researcher that diagnostic images will be obtained routinely in addition to the research imaging.

6.44 Management decisions should be based on the best evidence and in all cases will require referral to an appropriate medical expert.

6.45 The committee recommends that prior to a DXA scan being performed, written consent should be obtained from the individual concerned (see paragraph 6.24) and this should state that if a DXA scan shows an IF unrelated to the purpose of the procedure, then the image and resultant report should be referred to a medical doctor, who could review the information and determine whether further investigation was appropriate.

Conclusions

6.46 DXA is a technique for measurement of body composition involving a small dose of radiation. The technique is relatively straightforward to apply and has advantages over other laboratory-based methods in that it does not require a similar high level of specialised expertise to perform the analysis and it is less arduous and time-consuming for the athlete undergoing the test. The radiation dose from DXA is very low, but controls should be in place to limit its use to approved programmes of training or athlete assessment, as the long term value of the technique, although seemingly apparent to some proponents, still has to be established objectively. Use of a system of justification for examinations, similar to that required for medical examinations under IR(ME)R, would be appropriate. Data from scans performed should be analysed and results reported in the literature to create an evidence base for further use and development of the technique. If the scan reveals any IFs, the imaging data should be referred to a medical doctor for review, with the consent of the individual.

Chapter 7: Summary & conclusions

7.1 Dual-energy X-ray absorptiometry (DXA) is used in medicine to measure body composition and can assess ratios of fat to muscle for sportsmen and sportswomen that may be of value in relation to their sporting performance. Scans would generally be of the whole body, although scans of the limbs might be undertaken for certain purposes. The radiation dose from the assessment is very low, but under current legislation such scans can only be performed as part of a research programme or for medical reasons. The purpose of this report is to provide evidence to inform decisions about whether DXA assessments in relation to sporting performance should be considered to be a justified practice.

7.2 Athletes across a range of events and sports attempt to adjust and/or manage body weight to maximise their performance. For a given event, there is a good relationship between performance and body composition. As sport becomes more competitive, there is a drive to maximise individual performance and there is a perceived need to obtain more information on athletes' body make-up. As athletes prepare with different training regimes and diets, their bodies adapt and the composition of their body tissues changes. DXA provides a tool to measure these changes that could enable athletes and their trainers to gain a better understanding of how they are influenced by training and diet. However, there is limited evidence underpinning the use of DXA in elite athlete populations at the present time, so further research is required to develop a robust evidence-base.

7.3 Body composition and body weight are key factors in sports with weight classifications, such as boxing, judo and martial arts, and historic practices to lose body weight can have adverse effects on the health of athletes. DXA could provide a tool to assess body composition for determining the ability of athletes to perform in these weight categories.

7.4 If assessment of body composition can aid in the improvement of sporting performance then this can benefit the well-being of individual athletes and the morale of the team. The winning of medals and trophies can motivate and inspire young sportsmen and sportswomen, and can have life changing impacts on elite athletes. Such achievements will raise the spirits of team supporters and so can provide tangible benefit to larger groups of individuals and to society.

Techniques for measurement of body composition

7.5 DXA is one of several techniques available for assessing body composition. Alternative laboratory-based techniques involve assessing body density by HW or ADP, or the use of D_2O to estimate total body water content. DXA has practical advantages over these techniques in that measurements can be conducted reasonably rapidly (~5-25 minutes) and are not demanding on the participant. DXA can also provide regional estimates of body composition. Measurement of skinfold thickness may have a level of accuracy similar to DXA for measurement of changes in composition.

7.6 The reliability of newer DXA scanners appears to be adequate to allow detection of changes in fat mass or fat-free mass of the order of one kg. Scans to follow sequential changes should be undertaken using the same equipment, as there is no standardisation of the algorithms used to calculate body composition between manufacturers and scanner models. More information relating to body composition measurement is required to confirm the accuracy of newer scanner models.

7.7 Measurement conditions need to be standardised in order to obtain valid information. Soft tissue hydration or fluid distribution affect fat estimation by DXA and increase the precision error. Exercising prior to measurement, conducting measurements at different times of day, and consumption of food and drink prior to measurement all increase precision error.

7.8 In wheelchair athletes, regional tissue loss or atrophy may invalidate the assumptions made in other body composition techniques. As DXA may allow greater accuracy in regional assessment, it has potential for performing measurements on this group, although this has not been evaluated.

Radiation doses delivered by DXA

7.9 Whole body DXA scans from studies performed within the last 20 years give effective doses in the range of 2-10 µSv. Thus the amount of radiation used is comparable to a single postero-anterior chest X-ray (14 µSv), and similar to one day's exposure to natural radiation, and if there is any increase in lifetime risk of cancer incidence, it is less than 1 in 1 million. More data on scan parameters and dose are required relating to the exposure levels and field sizes used for body composition measurement to establish typical dose levels.

7.10 Since the risks are small, it would seem reasonable to justify the practice if there is an identified potential benefit to the scanned individual. However, an individual could be subject to large numbers of exposures if they continue to participate in sporting programmes using DXA scans over a period of many years. In addition, elite sportsmen and sportswomen are towards the younger end of the age spectrum and radiation risks are slightly greater at younger ages.

7.11 Controls could be implemented through restricting the use of DXA in relation to sporting performance, such that it is only undertaken as part of a formal monitored programme. This might involve inputs such as different training and/or dietary regimes and outputs relating to sporting performance that are evaluated in order to provide information through which benefits could be assessed.

7.12 The physiological changes that occur during pregnancy mean that any results are likely to be of little value, so the exposure during this time should not be justified.

7.13 Any radiation exposure should be kept as low as reasonably achievable, so good practice dictates that appropriate measures are taken to justify any exposure and ensure that the delivery is optimised to minimize the dose to the exposed individual. Where that individual is under 16 years of age, the frequency of DXA scans should be kept to a minimum.

Chapter 8: Recommendations

8.1 This report considers whether the practice of using DXA for assessment of body composition in relation to sporting performance and other non-medical practices should be justified based on information available at the time of the report. It addresses the need for controls on the use of the technique and the dose levels involved. It provides recommendations on guidelines required for the use of DXA for sporting assessment, taking account of current evidence while a more robust evidence-base is being established. Due to the lack of available evidence, the report is not able to evaluate other potential applications of DXA for non-medical practices. The following recommendations should be reviewed and developed as more evidence becomes available on the accuracy of the technique, its value in supporting sporting performance programmes and the dose levels involved, and its value for other non-medical practices.

Recommendation 1

8.2 Given the low level of possible risk and the potential benefit, COMARE recommends that the practice of DXA scans for the assessment of sporting performance and the effect of associated training regimes could be justifiable. However, since there is limited evidence of the value of DXA scans in relation to sporting performance, this practice should only be performed as part of a recognised training programme, and the committee further recommends that the following steps would be appropriate when undertaking such assessments:

i. an individual justification process including a risk assessment is carried out before approval of each programme using DXA. The assessment should include the perceived objectives from the training or dietary programme and could be planned in conjunction with a radiologist or other medical doctor with appropriate expertise to justify the programme. Estimates of dose to individuals undertaking the full programme should be made by a medical physics expert (MPE) with relevant expertise and presented in the form of a dose constraint.

ii. an individual justification procedure including a statement of the minimum interval between repeat scans and the maximum number of scans in the full programme. Although COMARE recognises that different sports will have different requirements for scan frequency and that seasonality is also a consideration, the frequency should take into account that DXA is only able to measure changes in body composition greater than about 1 kg in the fat or muscle component. As an indication, scans should not be repeated using intervals of less than six weeks and the committee suggests that the maximum number of scans an individual could be given over a year should be limited to six. If more frequent or higher numbers of scans were sought, this could require specific evidence to justify the procedure. Particular care should be taken when considering programmes involving children under 16 years of age.

iii. once such an individual justification process has been undertaken for a training programme, individuals might be referred onto the programme, within a formal structure that had been previously agreed.

iv. DXA examinations for sports performance assessments should be conducted under standardised conditions and times of day, according to standard protocols. Exposure data should be recorded to allow assessments to be made of the doses received. Where possible, an individual should use the same scanner in order to provide informative trend data.

v. DXA examinations for this purpose should not knowingly be performed on any individual who is pregnant.

vi. other methods for determining body composition should be carefully considered before deciding on the use of DXA. Alternative techniques such as skinfold measurement may be appropriate for assessing changes during training or dietary regimes.

8.3 Although the dose level of individual scans is minimal, consideration should also be given to cumulative doses that would arise from multiple scans over a sustained period of an athlete’s development and career. The steps for justification outlined above could provide reassurance that exposures of sportsmen and sportswomen are kept as low as reasonably practicable. Particular care should be taken when individuals are being regularly monitored from an early age.

Recommendation 2

8.4 COMARE recommends that following installation of DXA scanning equipment, an evaluation of the imaging and dose performance could be made a requirement. The equipment should be approved in terms of its suitability for the practice, including specifications of performance in body composition measurement. The evaluation should include measurements of the entrance surface dose levels for different examinations. If estimates are made of effective doses for scans that are likely to be performed, these could be used in subsequent risk assessments. Consideration should be given to requiring periodic DXA equipment calibration for assurance of imaging and dose performance.

Recommendation 3

8.5 Prior to commencement of a DXA scan programme for assessment of body composition, consent should be obtained from the sportsman or sportswoman setting out the agreement for performance of the procedures. Consent should also be sought regarding any incidental findings, with agreement for the image and the resultant report to be referred to a medical doctor, who could review the information and determine whether further investigation was appropriate. Consent for subsequent follow-up scans that formed part of the programme could be obtained verbally.

Recommendation 4

8.6 COMARE acknowledges that available information on the assessment of body composition using DXA is limited at the present time because of the small number of studies reported in the literature. The committee recommends further research into the use of DXA examinations for sports performance assessments be carried out. It is important that results from DXA use are analysed carefully to demonstrate and improve the value of the technique. Users should be encouraged to report their results in relevant peer-reviewed scientific journals. National professional bodies for particular sports could play a role in promoting collation and analysis of results.

8.7 The committee considers that more studies should be undertaken to provide information relating to body composition measurement by fan beam DXA scanners to confirm the accuracy of current models and software versions. These could be validated against robust methods, such as four compartment models.

8.8 Given that the dose levels reported for bone densitometry cover a range of more than a factor of ten, more data on scan parameters, exposure levels and areas of the body scanned would be beneficial to establish typical dose levels for body composition assessments. These should include determination of entrance surface dose and, an estimate of effective dose.

Recommendation 5

8.9 COMARE recognises that DXA could be used for other non-medical purposes. However there is currently no information to indicate that DXA is being used for such practices or any evidence to justify its use. The committee recommends the establishment of a procedure for the evaluation, and possible approval of any other non-medical uses of DXA proposed in the future, with properly constituted research to provide support for these practices. This could include a requirement for identifying potential benefits of any technique and a risk assessment including dosimetry data.

8.10 COMARE recognises that there are other radiation imaging techniques which could be used in making assessments relating to sporting performance. The committee recommends that a government approved authority or organisation might be identified that could review all of the potential future non-medical uses of radiological imaging techniques.

Recommendation 6

8.11 The committee notes the potential for uncontrolled proliferation of the DXA technique in mainstream activities, such as fitness programmes of individuals and sports programmes in schools. Commercial companies are offering DXA scans to the public to track changes in their fat and muscle. COMARE recognises that there is a regulatory process in place which enables justification of specified practices, and imposes requirements on subsequent exposures. The committee recommends that the relevant authorities give particular consideration to the use of DXA scanning for body composition measurement in relation to sporting performance and other recreational or commercial activities by all organisations, including commercial companies.

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Appendix A: Abbreviations & Glossary

ADP	air displacement plethysmography
ALARA	as low as reasonably achievable
ALARP	as low as reasonably practicable
BIA	bioelectrical impedance
BMD	bone mineral density
BMI	body mass index
BSSD	Basic Safety Standards Directive
CT	computed tomography
CV	coefficient of variation
D_2O	deuterium dilution
DCMS	Department for Culture, Media and Sport
DHSC	Department of Health and Social Care
DNA	deoxyribonucleic acid
DPA	dual photon absorptiometry
DXA	dual-energy X-ray absorptiometry
ECB	England and Wales Cricket Board
ESD	entrance surface dose
EU	European Union
FFM	fat-free mass
FM	fat mass
HW	hydrostatic weighing
ICRP	International Commission on Radiological Protection
IF	incidental finding
IR(ME)R	Ionising Radiation (Medical Exposures) Regulations 2000
JoPIIRR	Justification of Practices Involving Ionising Radiation Regulations 2004
kV	kilovolt
LSC	least significant change
MJ	megajoule
MPE	medical physics expert
MRI	magnetic resonance imaging
QUS	quantitative ultrasound
RED-S	Relative Energy Deficiency in Sport
SD	standard deviation
SKF	skinfold thicknesses
SPA	single photon absorptiometry
µGy	micro-Gray
µSv	micro-Sievert

ABSORBED DOSE	The quantity of energy imparted by ionising radiation to a unit mass of matter such as tissue. Absorbed dose has the units of joules per kilogram (J kg^{-1}) and the specific name gray (Gy), where 1 Gy = 1 J kg^{-1}.
ANDROID FAT	Fat deposited around the abdominal region.
ANTHROPOMORPHIC	Having human form or human attributes
BODY COMPOSITION	The proportion of fat and fat-free mass in human bodies. The percentages of fat, bone, water and muscle in the body.
BODY MASS INDEX	A measure of body fat based on height and weight that applies to adult men and women.
BONE DENSIOMETRY	A measure of the bone mineral content and density. It is used primarily to diagnose osteoporosis and to determine fracture risk.
CARDIAC	Pertaining to the heart.
COMPUTED TOMOGRAPHY (CT)	A special radiographic technique that uses a computer to assimilate multiple X-ray images into a two-dimensional cross-sectional image.
DOSE	A measure of the amount of radiation received. More strictly it is related to the energy absorbed per unit mass of tissue (*see Absorbed Dose*). Doses can be estimated for individual organs or for the body as a whole.
DOSIMETER	A device used to measure an absorbed dose of ionising radiation.
EFFECTIVE DOSE	Effective dose is the sum of the weighted equivalent doses in all the tissues and organs of the body. It takes into account the biological effectiveness of different types of radiation and variation in the susceptibility of different organs and tissues to radiation damage. Thus it provides a common basis for comparing exposures from different sources. Unit = sievert (Sv).
ENTRANCE SURFACE DOSE	Absorbed dose to the surface of the skin on which the X-radiation is incident. Commonly referred to as Entrance Surface Air Kerma.
EPIDEMIOLOGY	The study of factors affecting health and illness of populations, regarding the causes, distribution and control.
GRAY (Gy)	The international (SI) unit of absorbed dose. One gray is equivalent to one joule of energy absorbed per kilogram of matter such as body tissue.
GYNOID FAT	Fat deposited in the hip and thigh region.
HYPERTROPHY	The increase in the volume of an organ or tissue due to the enlargement of its component cells.

ICRP	International Commission on Radiological Protection. It consists of experts in radiology, genetics, physics, medicine and radiological protection from a number of countries. Established in 1928 it meets regularly to consider the research on the effects of radiation and publishes recommendations on all aspects of radiation protection including dose limits to man.
INCIDENCE	This is the number of new cases of a disease arising in a population over a specific period of time, usually one year.
IONISING RADIATION	Radiation that is sufficiently energetic to remove electrons from atoms in its path. In human or animal exposures ionising radiation can result in the formation of highly reactive particles in the body which can cause damage to individual components of living cells and tissues.
IR(ME)R PRACTITIONER	A registered health care professional, who is entitled to take clinical responsibility for an individual medical exposure in accordance with national requirements.
IRRADIATION	The process by which an item is exposed to radiation, either intentionally or accidentally.
JUSTIFICATION	Consideration that a medical exposure shall show a sufficient net benefit, weighing the total potential diagnostic or therapeutic benefits it produces, including the direct health benefits to an individual and the benefits to society, against the individual detriment that the exposure might cause, taking into account the efficacy, benefits and risks of available alternative techniques having the same objective but involving no or less exposure to ionising radiation.
LATERAL	Of, at, towards or from the side or sides.
LINEAR NO-THRESHOLD (LNT) HYPOTHESIS	The hypothesis used in radiation protection to estimate the long-term, biological damage caused by ionising radiation, which assumes that the damage is directly proportional (‘linear’) to the dose of radiation, at all dose levels and that any radiation exposure is always considered harmful with no safety threshold.
MAGNETIC RESONANCE IMAGING (MRI)	The use of nuclear magnetic resonance of protons to produce proton density images.
MEDICAL PHYSICS EXPERT (MPE)	An MPE is a physicist, expert in an area of medical radiation, appointed to support and advise the employer in the safe use of radiation for patients (Ionising Radiation (Medical Exposure) Regulations 2017, IR(ME)R 2017).
MODALITY	The method of application of a therapeutic agent or regimen.
MONTE CARLO SIMULATIONS	Monte Carlo simulations are a statistical approach for modelling X-ray interactions in and through tissue, and are used to determine an estimate of radiation dose.

NON-INVASIVE	Relating to any medical test or treatment that does not cut the skin or enter any of the body spaces.
NUCLEAR MEDICINE	A medical imaging specialty involving the application of radioactive substances in the diagnosis and treatment of disease
OPERATOR	Any person who is entitled to carry out the practical aspects of a medical exposure.
OPTIMISATION	Consideration that a medical exposure is conducted as efficiently and effectively as possible using the lowest reasonably practicable radiation exposure, consistent with the intended purpose. The optimisation process consists of a chain of responsibilities extending from appropriate manufacture, selection and maintenance of equipment to the exposure parameters selected for the individual examination.
OSTEOPOROSIS	A medical condition in which the bones become brittle and fragile from loss of tissue, typically as a result of hormonal changes, or deficiency of calcium or vitamin D.
PAEDIATRIC	Of, or relating to, the medical care of children.
PATIENT DOSE	The ionising radiation dose to a patient or other individual undergoing a medical exposure.
PHANTOM	Object generally comprised of tissue substitute materials used to simulate a patient or part thereof.
PHOTON	A particle representing a quantum of light or other electromagnetic radiation. A photon carries energy proportional to the radiation frequency, but has zero rest mass.
RADIOLOGIST	A medically qualified doctor who specialises in the use of imaging techniques (X-rays, ultrasound, CT, MR, fine needle biopsy, etc) for diagnosis (diagnostic radiologist) or one who specialises in the use of imaging techniques in assisting treatment – for example, in inserting catheters into blood vessels or in choking the blood supply of a tumour by injection of a type of glue (interventional radiologist).
RADIONUCLIDE	A type of atomic nucleus which is unstable and which may undergo spontaneous decay to another atom by emission of ionising radiation (usually alpha, beta or gamma).
RADIOSENSITIVITY	The relative susceptibility of cells, tissues, organs, organisms, or any other substances to the effects of radiation.
REFERRER	A registered health care professional who is entitled in accordance with the employer's procedures to refer individuals for medical exposure to a practitioner.

RISK	The probability that an event will occur, e.g. that an individual will become ill or die before a stated period of time or age. This is also a non-technical term encompassing a variety of measures of the probability of a (generally) unfavourable outcome.
SIEVERT (Sv)	The international (SI) unit of effective dose obtained by weighting the equivalent dose in each tissue in the body with the ICRP-recommended tissue weighting factors and summing over all tissues. Because the sievert is a large unit, effective dose is commonly expressed in millisieverts (mSv) – i.e. one-thousandth of one sievert. The average annual radiation dose received by members of the public in the UK is 2.7 mSv.
SPATIAL RESOLUTION	The ability of the imaging modality to differentiate two objects.
SPECTRA	A characteristic series of frequencies of electromagnetic radiation emitted or absorbed by a substance
STOCHASTIC	Stochastic effect or ‘chance effect’ is a classification of radiation effects that refers to the random, statistical nature of the damage. The severity is independent of dose. Only the probability of an effect increases with dose.
SUBCUTANEOUS FAT	Fat situated under the skin.
SUPINE	(Of a person) lying face upwards.
THERMOLUMINESCENCE	The property of some materials of becoming luminescent when subjected to high temperatures.
TRANSMISSION MEASUREMENT	Measurement of the proportion of a radiation beam transmitted through an object, such as tissues of the body.
ULTRASOUND	The use of ultrasonic waves for diagnostic or therapeutic purposes, specifically to visualise an internal body structure, monitor a developing foetus, or generate localised deep heat to the tissues.
VERTEBRAL	Of or relating to the spinal vertebra or vertebrae.
VISCERAL FAT	Fat found around the major internal organs.
WHOLE BODY SCAN	Scan of whole body from head to toe.
X-RAY	An image obtained using high energy radiation with waves shorter than those of visible light. X-rays possess the properties of penetrating most substances to varying extents, of acting on a photographic film or plate (permitting radiography), and of causing a fluorescent screen to give off light (permitting fluoroscopy). In low doses X-rays are used for making images that help to diagnose disease, and in high doses to treat cancer.

Appendix B: Guidelines for the implementation of the safe and effective use of DXA linked to sport performance assessment

B.1 There should be a process of individual justification before carrying out a DXA scan as required under the (IR(ME)R, 2017). Definitions for the individual roles for implementing this process are set out below.

a. **Employer**: The employer is the organisation providing the service that has registered its use of DXA scanning with the Health and Safety Executive under the Ionising Radiations Regulations (IRR, 2017). The employer must put in place the procedures required by Schedule 2 of the IR(ME)R 2017 regulations (IR(ME)R, 2017).

b. **Practitioner**: The practitioner is the person with responsibility for justifying each exposure and must be a registered healthcare professional who has been appropriately and formally entitled by the employer responsible for the procedure. The practitioner should have a full knowledge of the potential benefit and detriment associated with the procedure, so all practitioners would need to be adequately trained to undertake the task for DXA scans in relation to sporting performance. The regulations give the practitioner a broad set of responsibilities with respect to justification, including the need to pay particular attention to medical imaging exposures of children.

c. **Operator**: The operator is any appropriately entitled person who carries out a practical aspect associated with a radiological exposure. An operator usually will carry out a variety of functions, so the functions and responsibilities (scope) of individual operators should be clearly defined within standard operating procedures. Examples of practical aspects are identification of the individual, authorisation of an individual exposure in accordance with written guidelines issued by a practitioner, operation of the radiation equipment and evaluation of the resulting image. Operators must be appropriately trained.

d. **Medical Physics Expert (MPE)**: Employers are required to involve MPEs as appropriate in issues concerning DXA scanning. The MPE is an operator whose role is to undertake tasks such as giving advice on optimisation, equipment performance, dosimetry for individuals, development and use of new techniques, and radiation protection of the individual being examined. MPEs should be adequately trained and formally appointed by the employer. The duties of an MPE are set out in Schedule 3 of IR(ME)R 2017.

Duties of an employer providing a service using any equipment emitting ionising radiation

B.2 An employer operating DXA or other equipment emitting radiation used for scanning of human subjects for assessments in relation to sporting activity must register the equipment with the Health and Safety Executive and comply with the Ionising Radiations Regulations (IRR, 2017).

B.3 Any employer operating DXA or other equipment emitting radiation used for scanning of human subjects for assessments in relation to sporting activity must have a suite of written procedures asset out in Schedule 2 of IRMER 2017.

B.4 An employer would be required to establish written protocols, based on recommendations of the practitioner, which provide equipment settings specific to each type of examination and machine. The protocols could include upper limits on the frequency with which scans were performed, and an upper limit on the number performed in a year. Special care should be taken in specification of limits if the programme will involve individuals under the age of 16 years.

B.5 The employer would be responsible for ensuring that practitioners and operators of the equipment were both adequately trained to undertake their respective roles and engaged in continuing education and training. Training would relate to performance of the procedure, evaluation of the clinical image, application of the technique and development of expertise relevant to its use.

B.6 The employer would be responsible for ensuring that the DXA equipment is of such design, and is installed and maintained to be capable of restricting the exposure of persons undergoing scans, as far as is reasonably practicable. The employer would also be responsible for ensuring that a quality assurance system was in place in order to maintain the equipment performance.

Evaluation of results

B.7 All images must be evaluated (reported) by a person entitled as an operator by the employer to so do. In this case the operator should have appropriate training in the interpretation of DXA images in relation to sports medicine or any other imaging procedure employed. The responsibility for ensuring that this requirement of the regulation is complied with lies with the employer. The employer might consider detailing in his/her procedures how and when the evaluation was to be made and what the process was to ensure that a record of the evaluation was made. Examples of operators for evaluation of results might include doctors, radiographers, sports scientists, medical physicists, and nutritionists.

B.8 This evaluation might detail the resulting findings relating to body composition to be given to the individual athlete examined, and with their consent be passed to those overseeing the training programme.

B.9 The employer’s procedure should also include steps to be followed when an IF unrelated to the purpose of the examination is identified. This should include a process whereby the image and resultant report is, with the prior consent of the individual examined, passed to a medical doctor who could review the information and determine whether further investigation was appropriate.

Appendix C: Explanation of risk from exposure and consent

C.1 An explanation of the procedure should be given to the individual being examined that was sufficient to enable them to understand what was involved and give a perception of the risks and benefits from the practice and the possibility of IFs, prior to obtaining their consent for the procedure. This is a regulatory requirement under IR(ME)R 2017 and must form part of the employers written procedures.

C.2 It would be appropriate for individuals over 18 years old having an examination to be asked to give consent themselves before the examination was carried out.

C.3 For children aged 16 or 17 years old, it may be good practice for the explanation to be given to the child and their family. However, the child could give their consent for the examination. In the case of children under 16 years old, the explanation could be given both to the child and to the person(s) with parental responsibility, generally the parent or guardian (The Children Act (1989; 2004). The child could be assessed to determine whether they had sufficient understanding to make up their own mind about the benefits and risks (Gillick competence). It would not be appropriate for parents to override a child’s refusal to undergo a procedure (DH, 2008; DH, 2009; NSPCC, 2017).

Appendix D: The Committee on Medical Aspects of Radiation in the Environment

D.1 The Committee on Medical Aspects of Radiation in the Environment (COMARE) was established in November 1985 in response to the final recommendation of the report of the Independent Advisory Group chaired by Sir Douglas Black (Black, 1984). COMARE's terms of reference are:

> "*to assess and advise Government and the Devolved Authorities on the health effects of natural and man-made radiation and to assess the adequacy of the available data and the need for further research*"

D.2 In the course of providing advice to Government and the devolved authorities for over thirty years, COMARE has published to date 17 major reports and many other statements and documents mainly related to exposure to naturally occurring radionuclides, such as radon and its daughters, or to man-made radiation. The most recent published COMARE report provided an update on the incidence of childhood leukaemia in the vicinity of the nuclear installations at Sellafield and Dounreay.

D.3 The Department of Health and Social Care asked COMARE to review the evidence on the practice of using DXA scans for sports performance assessments and other non-medical practices within the UK. COMARE established a Medical Practices Subcommittee (DXA), with membership consisting of committee members and external experts, to conduct this work. The Subcommittee's terms of reference are:

> *"To advise COMARE on the health effects, benefits and risks arising from the use of ionising radiation in DXA in non-medical practices through assessment of the available data and to inform COMARE of further research priorities."*

D.4 When the Subcommittee had finished its review, the report was presented to COMARE for consideration by the full committee, with the aim that the information would be presented to the Department of Health and Social Care in due course. That information is contained in this, our eighteenth report.

COMARE reports

Seventeenth report	Further consideration of the incidence of cancers around the nuclear installations at Sellafield and Dounreay. PHE, Chilton, September 2016
Sixteenth report	Patient radiation dose issues resulting from the use of CT in the UK. PHE, Chilton, August 2014
Fifteenth report	Radium contamination in the area around Dalgety Bay. PHE, Chilton, May 2014
Fourteenth report	Further consideration of the incidence of childhood leukaemia around nuclear power plants in Great Britain. HPA, Chilton, May 2011
Thirteenth report	The health effects and risks arising from exposure to ultraviolet radiation from artificial tanning devices. HPA, Chilton, June 2009
Twelfth report	The impact of personally initiated X-ray computed tomography scanning for the health assessment of asymptomatic individuals. HPA, Chilton, December 2007
Eleventh report	The distribution of childhood leukaemia and other childhood cancer in Great Britain 1969–1993. HPA, Chilton, July 2006
Tenth report	The incidence of childhood cancer around nuclear installations in Great Britain. HPA, Chilton, June 2005
Ninth report	Advice to Government on the review of radiation risks from radioactive internal emitters carried out and published by the Committee Examining Radiation Risks of Internal Emitters (CERRIE). NRPB, Chilton, October 2004
Eighth report	A review of pregnancy outcomes following preconceptional exposure to radiation. NRPB, Chilton, February 2004
Seventh report	Parents occupationally exposed to radiation prior to the conception of their children. A review of the evidence concerning the incidence of cancer in their children. NRPB, Chilton, August 2002
COMARE and RWMAC* joint report	Radioactive contamination at a property in Seascale, Cumbria. NRPB, Chilton, June 1999
Sixth report	A reconsideration of the possible health implications of the radioactive particles found in the general environment around the Dounreay nuclear establishment in the light of the work undertaken since 1995 to locate their source. NRPB, Chilton, March 1999
Fifth report	The incidence of cancer and leukaemia in the area around the former Greenham Common Airbase. An investigation of a possible association with measured environmental radiation levels. NRPB, Chilton, March 1998
Fourth report	The incidence of cancer and leukaemia in young people in the vicinity of the Sellafield site, West Cumbria: further studies and an update of the situation since the publication of the report of the Black Advisory Group in 1984. Department of Health, London, March 1996

* Radioactive Waste Management Advisory Committee.

COMARE and RWMAC* joint report	Potential health effects and possible sources of radioactive particles found in the vicinity of the Dounreay nuclear establishment. HMSO, London, May 1995
Third report	Report on the incidence of childhood cancer in the West Berkshire and North Hampshire area, in which are situated the Atomic Weapons Research Establishment, Aldermaston and the Royal Ordnance Factory, Burghfield. HMSO, London, June 1989
Second report	Investigation of the possible increased incidence of leukaemia in young people near the Dounreay nuclear establishment, Caithness, Scotland. HMSO, London, June 1988
First report	The implications of the new data on the releases from Sellafield in the 1950s for the conclusions of the Report on the Investigation of the Possible Increased Incidence of Cancer in West Cumbria. HMSO, London, July 1986

* Radioactive Waste Management Advisory Committee.

COMARE Membership

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Assessors in attendance representing the following organisations	Department for Business, Energy & Industrial Strategy Department for Communities and Local Government Department for Education Department of Health and Social Care Department of Health (Northern Ireland) Environment Agency Food Standards Agency Food Standards Scotland Health and Safety Executive Information Services Division, NHS National Services Scotland Ministry of Defence Nuclear Decommissioning Authority Office for Nuclear Regulation Office for National Statistics Public Health England Scottish Environment Protection Agency Scottish Government Welsh Government

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