



Radiation protection in non-ionizing and ionizing body composition assessment procedures

Samantha Cornacchia¹, Luciana La Tegola², Arcangela Maldera¹, Elena Pierpaoli³, Umberto Tupputi², Giovanni Ricatti², Laura Eusebi⁴, Sergio Salerno⁵, Giuseppe Guglielmi^{2,6}

¹Medical Physics Unit, Dimiccoli Hospital Barletta, Barletta, ASL Barletta-Andria-Trani, Italy; ²Department of Clinical and Experimental Medicine, Foggia University School of Medicine, Foggia, Italy; ³ASUR Marche, Medical Physics Unit, Ascoli Piceno, Italy; ⁴Radiologia Ospedale “Carlo Urbani”, Jesi, Italy; ⁵Department of Radiology, University of Palermo, Palermo, Italy; ⁶“Dimiccoli” Hospital, University Campus of Barletta, Barletta, Italy

Correspondence to: Prof. Giuseppe Guglielmi. Department of Clinical and Experimental Medicine, Foggia University School of Medicine (<http://www.unifg.it>), Viale L. Pinto, 1 71121, Foggia, Italy; “Dimiccoli” Hospital, University Campus of Barletta, Barletta, Italy.
Email: giuseppe.guglielmi@unifg.it.

Abstract: Body composition assessment (BCA) represents a valid instrument to evaluate nutritional status through the quantification of lean and fat tissue, in healthy subjects and sick patients. According to the clinical indication, body composition (BC) can be assessed by different modalities. To better analyze radiation risks for patients involved, BCA procedures can be divided into two main groups: the first based on the use of ionizing radiation (IR), involving dual energy X-ray absorptiometry (DXA) and computed tomography (CT), and others based on non-ionizing radiation (NIR) [magnetic resonance imaging (MRI)]. Ultrasound (US) techniques using mechanical waves represent a separate group. The purpose of our study was to analyze publications about IR and NIR effects in order to make physicians aware about the risks for patients undergoing medical procedures to assess BCA providing to guide them towards choosing the most suitable method. To this end we reported the biological effects of IR and NIR and their associated risks, with a special regard to the excess risk of death from radio-induced cancer. Furthermore, we reported and compared doses obtained from different IR techniques, giving practical indications on the optimization process. We also summarized current recommendations and limits for techniques employing NIR and US. The authors conclude that IR imaging procedures carry relatively small individual risks that are usually justified by the medical need of patients, especially when the optimization principle is applied. As regards NIR imaging procedures, a few studies have been conducted on interactions between electromagnetic fields involved in MR exam and biological tissue. To date, no clear link exists between MRI or associated magnetic and pulsed radio frequency (RF) fields and subsequent health risks, whereas acute effects such as tissue burns and phosphenes are well-known; as regards the DNA damage and the capability of NIR to break chemical bonds, they are not yet robustly demonstrated. MRI is thus considered to be very safe for BCA as well US procedures.

Keywords: Body composition (BC); ionizing radiation (IR); non-ionizing radiation (NIR)

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Introduction

Body composition (BC) is defined by Wang *et al.* (1) as the branch of biology that deals with the *in vivo* quantification of human body components. Body composition assessment (BCA) allows us to evaluate the health status in terms of nutritional status and to evaluate the efficacy of primary and secondary preventive nutritional strategies. It can be used for many clinical purposes: it's useful for assessing cachexia (2), often related to other serious disease (e.g., cancer) (3), and sarcopenia, a condition of increasing interest to the scientific community for its multiple clinical and socio-economic implications. BC can also estimate metabolic risk. It is well known that an excessive quantity of adipose tissue (AT) is related to increase morbidity and mortality (4). Metabolic risk, for instance, strongly depends on fat distribution: central obesity and ectopic fat accumulation are important metabolic risk factors (5,6). Other features, such as waist circumference and waist-to-hip ratio are also strongly associated with metabolic risk (7,8). Cardiac risk (9), liver disease (10), type 2 diabetes (11,12) and cancer (13,14) are related linked to large amounts of visceral adipose tissue (VAT). AT contains approximately 80% fat; the rest is water, minerals and proteins (15). Body mass index (BMI) is the main parameter for estimating body fat, but it does not provide information on the local distribution in the body (16-18). BC assessment usually involves middle-old aged people for diagnosis of osteoporosis and sarcopenia but it is also performed on children. Indeed, many studies using BC measures have been published on child obesity (19,20), on the association between the pulmonary function in children with cystic fibrosis (21) and on the prevalence of under- and overweight children with neurodisability (22).

Medical techniques for BC assessing provide precise information about the quantity (23), quality and distribution of AT and lean tissue (LT), some using ionizing radiation (IR), such as computed tomography (CT) and dual energy X-ray absorptiometry (DXA) (24), others using non-ionizing radiation (NIR), such as magnetic resonance imaging (MRI) (25) and Ultrasounds (US) (mechanical waves) (26). Radiation protection issue has to be taken into account especially in children and younger patient's irradiation. The risk of cancer for a 20-year-old patient is doubled compared with a patient aged 40 and is 50% lower for a patient aged 60 (27). Moreover, children are more radiosensitive, 3 to 4 times more sensitive than adults (28).

The new European Directive 59/2013 (29) enforced

the need to justify medical exposure to IR and confirmed the process of optimization by the use of diagnostic reference levels (DRL) and close collaboration with medical physicists. The Directive also requires that adequate information about the benefits and risks associated with the radiation dose must be provided for patients. Cornacchia *et al.* (30) have recently analyzed what information should be reported in radiological report according to art.58 (b) of Directive 59. Regarding NIR, the risks for the population and workers are respectively described in European Directives 519/1999 (31) and 35/2013 (32). In particular the Directive 35/2013 covers all known direct biophysical effects and indirect effects caused by electromagnetic fields (EMF), but it specifies that long-term effects are not yet well-confirmed by scientific communities.

The most important difference between IR and NIR is the radiation energy used to acquire information: IR carries enough energy to remove electrons from atoms (ionization process) and to leave atoms in an unstable state, while NIR is not able to do this. Risks associated with IR are well known and there are many publications related to this issue. On the contrary, NIR effects, in particular on how weak EMF (as used in MRI) could affect human health, are still under discussion (33).

Given the importance of BCA in routine clinical practice we analyzed the different techniques available for BCA and suggested some recommendations to reduce patient's health risks associated with IR and NIR.

Material and methods

In order to better evaluate the radiation protection issues and risks on health, BCA techniques have been divided into two groups: one using NIR (MRI) and the other IR-based (DXA and CT). US belongs to a different group based on mechanical waves.

NIR techniques

MRI

MRI is mostly used in BCA to quantify the volume of AT (34) and muscles (35). High soft-tissue contrast in combination with absence of IR and increasing availability makes MRI the preferred method of choice and enables true volumetric three-dimensional imaging even in healthy volunteers and infants. The measurements of regional AT and LT, as well as diffuse fat infiltration in other organs, can be better obtained using Dixon imaging, where the

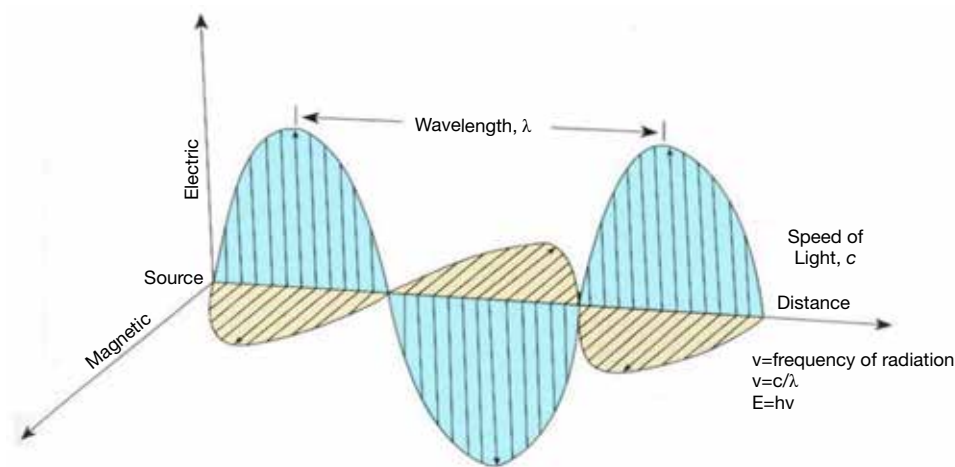


Figure 1 Schematic representation of the electromagnetic wave with its main physical features.

different magnetic resonance frequencies of protons in fat and water are used to separate the two signals into a water image and a fat image (36). Limitations of MRI include the high cost of acquiring the scan and the fact that it is not feasible for persons with claustrophobia (37). In recent years MRI has shown promising results in accurate measurement of BC (38). MRI is the more appropriate diagnostic method for muscle pathology progression (39); in particular, fat referenced MRI (40–44) provides a powerful tool for advanced BC assessment.

NIR effects on biological tissue

Radiations used in MRI procedures belonging to NIR not able to strip electrons from atoms; the supposed damage of NIR to DNA molecule and the capability of breaking chemical bonds have not yet been robustly demonstrated (45). Currently, there are some controversial studies reporting an increase in DNA damage following NIR exposure (46). Patients undergoing an MR investigation are exposed to a mixture of a static magnetic field (SMF), time-varying gradient magnetic fields (GMF) and pulsed radiofrequency fields (RF). The electromagnetic (EM) field represents a group of EM waves travelling with a certain frequency and energy, at the speed of light. In *Figure 1* a schematic representation of the EM wave and its main physical features is shown.

Exposure to SMF—zero frequency

The earth SMF is 50 micro Tesla (μT) and varies from 30 to 70 μT , depending on the geographic location. During MR examinations, the patient is exposed constantly to a

SMF (B_0), representing the maximum field intensity of the machine magnetic field, measured in Tesla units (typically 1.5, 2 or 3 T). The effect of B_0 on water hydrogen protons in the human body is the spatial orientation of their magnetic moments along the direction of B_0 (typically Zeta-axis, i.e., the patient's bed direction). Moreover, magnetic fields in the human body can move electric charges, for example blood cells moving in the field can reduce their velocity flowing through blood vessels (47). With regard to the clinical effects of SMF on tissue, it can be assumed that conventional magnetic resonance scanners operating up to 2 T are safe for patients. As far as long-term effects are concerned, a few epidemiological studies have been conducted on workers exposed to a moderate static field (several tens of mT) with different endpoints including cancer incidence and chromosome aberration (48–51). For many reasons, ranging from methodological limitations to the very small numbers of people involved, these studies can be considered to be unresolved.

Exposure to GMF—10–100 kHz frequency range or low frequency (LF)

GMF are used to build an MR image and they are time-dependent (dB/dt), overlapping to main field B_0 in order to spatially select signals from different positions in the body. Gradients generate electric fields and currents inside the body that can interfere with the physiological electric fields and flows. Different exposure thresholds (depending on field frequency) can be established above which induced internal fields can cause reversible effects on excitable cells (phosphenes) (52), nerves stimulation

Table 1 Summary of non-ionizing radiation effects

Magnetic field type	Physical interaction	Short-term effect	Long-term effect
Static magnetic field	Ferromagnetic attraction force	Object in the gantry	No evidence
	Electric charges motion	Nausea, vertigo, metallic taste	
Low frequency field (gradients)	Induced electric fields and current	Phosphenes, nerve stimulation, electric charge on the skin [§] , cardiovascular-related, tissue burns [†]	No evidence
Radio frequency field	Electronic interference	Wrong functioning of implantable active devices	No evidence
	Energy transfer-heating	Tissue burns	

[§], reversible effects; [†], irreversible effects.

(53,54) and electric charge effects on the skin. Irreversible effects such as cardiovascular-related or tissue burns can occur when thresholds are exceeded (55). Relating to long-term effects, actual evidence for cancer in adults from LF exposure does not exist; there are a considerable number of epidemiological studies (56,57). After these studies, the International Agency for Research on Cancer (IARC) in 2002 classified LF fields as “possibly carcinogenic to humans” (category 2B) (58).

Exposure to radio frequency (RF)—MHz frequency range or high frequency (HF)

At the beginning of the MR exam, the scanner applies an RF field in the form of short pulses at specific intervals and supplies the useful energy to hydrogen nuclei for inducing the physical phenomena of resonance. Consequently, spin vectors that rotate with precessional mote amplify this rotation. Effects of RF on patients are associated with tissue heating, quantified through the physical quantity specific absorbed rate (SAR), available on the MR scanner for each acquisition sequence. The SAR is the ratio between the energy transfer over time to a volume and the mass of that volume (Watt/kg). It is well known that above a certain level (thermal threshold) of RF exposure and temperature rise, heat-stroke and tissue damage (burns) can occur (59). Below the thermal threshold, many studies reported no conclusive evidence of adverse effects on health (60). At present, epidemiological data have not revealed possible health effects from chronic whole-body exposure and further researches are required. Finally, a consideration concerning patient safety has to be made: the interaction of RF with electronic implantable devices, such as pacemakers or defibrillators, can seriously compromise the proper operation of such devices. *Table 1* summarizes the effects of the three fields described above.

IR techniques

DXA

DXA is the most popular diagnostic imaging method for quantifying fat, lean and total body bone mineral content; it works on the variation in the attenuation of two low-energy X-ray beams through tissues, due to their different composition. According to the World Health Organization (WHO), DXA is the gold standard for bone mineral density (BMD) measurements (61), but currently it has also been used to estimate total and regional body fat and lean. Given that it is fast, requiring 10 to 20 minutes to complete, has minimal radiation exposure (<10 micro Sieverts, μSv) and needs little technical skill for the operator (62), it is employed also for this scope. DXA estimates of BC are also affected by some limitations: differences among manufacturers in technology, models, and software employed (63) and physical limitations mainly due to body size (large patients don't fit in the scan area) (64).

CT

CT gives a three-dimensional high-resolution image volume of the complete or selected parts of the body and it uses the differences in X-rays attenuations between lean soft tissue and AT to exploit the BCA (65). The standard CT protocol for BCA consists of a single abdominal slice through the level of L3–L4, the region of highest amount of abdominal fat. Moreover, CT can provide a contribution in cardio-metabolic risk stratification, analyzing pericardial fat, intrathoracic fat and epicardial fat (66,67). In addition, CT can accurately determine fat in the liver. It is, however, significantly less accurate for liver fat (<5%) which limits its use to diagnose low-grade steatosis. As far as micro-CT is concerned, it plays a significant role in small animals (mice), while there is still not enough evidence to suggest

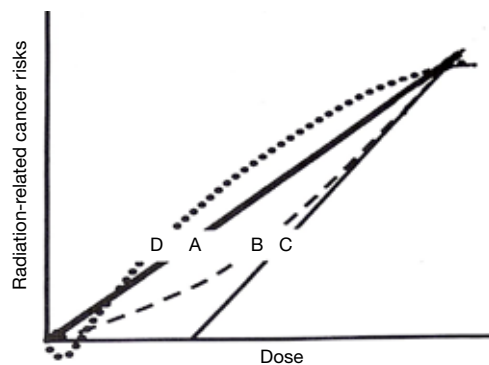


Figure 2 Schematic representation of different possible extrapolations of measured radiation risks down to very low doses. Curve A, linear (LNT model); curve B, linear quadratic; curve C, with threshold; curve D, hormetic. Adapted from (79). LNT, Linear No-threshold Theory.

its routine use in humans. Finally, the term quantitative CT (QCT) indicates CT procedures where a standard calibration converts Hounsfield units (HU) of the CT image to BMD values.

IR effects on biological tissue

IR effects relate to the large energy loss of radiation within the body. The ratio between the energy absorbed by a biological tissue and the mass of volume where the energy is released, is defined absorbed dose D (measure unit Gray). The equivalent dose H (measure unit Sievert) takes into account the features of different radiations, whilst the effective dose E (measure unit Sievert) considers the different tissue radio-sensitivity. Effective dose is a radiation protection quantity calculated as the product of the equivalent dose and tissue-weighting factors; the International Commission on Radiation Protection (ICRP) recommends it to assess health risks related to low doses (68).

When IR interacts with water molecules in the body, it can create free radicals able to interact with DNA and cause strand breaks or base damage which is usually repaired; if not, a gene mutation or chromosome translocation can occur and lead to cancer, following a stochastic process, at any level of radiation exposure. Many studies have confirmed the evidence of radiation-induced cancer risk, from first reports of leukemia arising in radiation workers (69) until recent articles (70,71). Concerning radiation doses, studies on Japanese bomb survivors report an effective dose of 100 mSv, above which there is clear

evidence of radiation-induced cancer risk (72). For doses below 100 mSv (range, 10–100 mSv), data provided by epidemiological studies are controversial: some researchers suggested an increased cancer risk (73–75), whereas others reported no evidence of carcinogenic effect from epidemiological data (76,77). Current epidemiological studies do not offer the statistical power to detect an increased risk below 10 mSv (28), though we cannot exclude it.

Linear No-threshold Theory (LNT) is the most accredited model to describe the relationship between cancer risk and low-doses (below 100 mSv): it predicts the direct proportionality between the two, extrapolating the excess of cancer risk from higher doses (78) (*Figure 2*, curve A). The central point of the LNT model is the assumption that the event leading to carcinogenesis is due to “one-track action”: a single electron track (produced during the ionization process) can cause one or more DNA double strand breaks; the track number is directly proportional to the dose and thus the cancer risk is proportional to the dose, with any dose. Many studies support the one-track assumption (80–83). The BEIR VII report, the ICRP and the United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (84) ratified the LNT model. The most notably controversy about this model comes from the French Academy of Sciences report. Furthermore, LNT does not represent the only model explaining the correlation between cancer and low doses. Data from the Life Span Study (85) reporting incidence of leukemia at intermediate doses, for example, correlate with a linear-quadratic curve (*Figure 2*, curve B); if the capability of immune system of removing pre-malignant and early tumor cells is considered, the curve trend is represented in *Figure 2*, curve C, providing the possibility of a practical threshold. Other investigators suggested that low dose radiation could have beneficial effects in reducing cancer (*Figure 2*, curve D), taking into account genomic instability, DNA damage prevention, apoptosis and bystander effects (86). IR can also interact directly with DNA, but this process is more likely for alpha and beta particles. Below 100 mGy of the acute organ absorbed dose, early or late tissue reactions can occur due to multiple damages to cells (79).

US

US represents a practical non-invasive technique to evaluate BC in a first step of assessment. It allows us to measure in real-time subcutaneous fat thickness and the cross -

Table 2 Dose-area product and entrance skin dose for different DXA machines (98,99)

Machine	DAP spine study (mGy·cm ²)	ESD (μGy)
Lex X05	30	–
Hologic 4500	36	200
Lunar Prodigy	10	37
Lunar DPX	5	10.25
Norland XR 36	2	0.9–44.4
Hologic QDR 1000	–	60
Hologic QDR 2000	–	138
Lunar Expert	–	895

DXA, dual energy X-ray absorptiometry; DAP, dose-area product; ESD, entrance skin dose.

sectional areas of superficial muscles of the target structure, providing through predictions equations estimation of percent body fat and assessment of muscle (87,88). The use of ultrasonography has traditionally had some advantages, such as the low cost, the speed of execution, the absence of IR, but it also has some limitations due to operator experience, absence of standardized procedure and site-specific cut-off points, artifacts (89-91). Therefore, its use in the determination of BC is currently limited.

US effects on biological tissue

USs are mechanical waves propagating in a medium. When crossing biological tissue, the carried energy reduces with depth: tissue structures met along the beam path can reflect or absorb energy. We can divide interaction mechanisms of US into two categories: thermal and non-thermal. The thermal effect corresponds to temperature rising and depends on the physical quantity I_{SPTA} (spatial peak temporal average intensity), expressed in mWatt/cm² unit. Diagnostic levels of US can produce temperature rises that may be dangerous for sensitive organs and embryo/fetus (92). The non-thermic effect translates into a mechanical effect arisen from wave pressure. Cellular and subcellular structures exposed to US undergo torsion, rotational and translational forces due to the non-homogeneity of acoustic energy. These forces can cause flows and vortices in fluids exposed (acoustic streaming), a phenomenon more relevant when investigating bladder, large vessels or amniotic liquid (93). Biological effects of a non-thermal origin have been reported in animals (94), but are not demonstrated in humans, except when a micro-bubble contrast agent was present (92).

Results

In this section, we reported radiation doses involved in different techniques based on IR and we suggested how to apply the optimization process to them. Furthermore, we described technical aspects and provided the main recommendations for NIR-based procedures, in order to reduce potential harms to patient.

IR techniques

As for BCA procedures, a general consideration is inherent for those patients with high BMI and thus with a greater thickness of the investigated area. Obese patient, indeed, typically will receive a greater effective dose in radiographic examinations with respect to normal weight patients (95,96). Moreover, for patients undergoing CT, radiation dose reduction techniques cannot be used in patients with high BMI, because the noise level in images remains too high after the application of reduction dose algorithms (97).

DXA

Table 2 shows dose-area product (DAP) and entrance skin dose (ESD) measured with different DXA equipment, for spine study. DAP is the generally accepted standard for reference dose estimation in planar radiology: it is the incident air dose measured by a DAP meter multiplied by the field's area used for the study. ESD and DAP in each exam are correlated to organ dose. Mokhtari-Dizaji *et al.* (100) find a significant correlation between the dose at the scan center and thyroid and uterus surface doses, measured using a phantom and thermo-luminescent

Table 3 Thyroid and uterus surface doses, calculated using a phantom with thermo-luminescent dosimeters; dose at scan centre was 6 µGy (101)

Organ	Absorbed dose (µGy)
Uterus	1.21±0.33
Thyroid left lobe	1.28±0.25
Thyroid right lobe	1.18±0.17

Table 4 Summary of effective doses in typical DXA exams

Patient study	Effective dose (µSv)
Women osteoporosis (100,101)	0.1–3.6 [†]
Total body (102)	0.1–75
Children exams (99)	0.4–5.4

[†], depending on investigated anatomical district. DXA, dual energy X-ray absorptiometry.

Table 5 Effective doses involved in different BCA procedures. Adapted from (27)

Technique	Effective dose (mSv)
DXA	0.001–0.075
Radiograph	0.3–0.7
CT	3
Periferical CT	0.01–0.03

BCA, body composition assessment; CT, computed tomography; DXA, dual energy X-ray absorptiometry.

dosimeter. *Table 3* reports results and shows the dose at scan center (6 µGy). *Table 4* resumes the effective doses in typical DXA exams. Although DXA doses are very low, Sheahan *et al.* identified three potential sources of overexposure: difference between beam area selected by operator and actual exposed area, incorrect fan-beam angle (the beam should fit exactly the detector area) and inadequate X-ray tube filtration (98). Doses involved in DXA exams belong to a range (<10 mSv) below which no epidemiological evidence exists for increased cancer risk. On the other hand, a small risk increase is always present when considering LNT model.

CT

Radiation doses involved in CT examination are orders of a magnitude greater than DXA doses. Depending on the CT protocol, indeed, radiation dose levels associated

to examination ranges from 0.6 to 3 mSv for a dedicated QCT. Moreover, it is well known that there is a large CT dose variability among different institutions (24). As an example, Damilakis *et al.* reported a typical dose level in an adult abdomen CT examination of about 8 mSv and stressed the need to optimize protocols, preferring automatic exposure control (AEC) protocols to fixed-mAs protocols, reaching a dose sparing ranging from 15% to 60% (24). The need to reduce patient dose in CT-based techniques led us to explore the possibility of optimizing protocols without loss of density information. Mei *et al.* (103) demonstrated that many parameters characterizing bone structures such as BMD, bone fraction and trabecular thickness are robust in low-dose protocols, allowing a dose reduction of about 90%. Results reported in the article specify that these parameters are more stable if the dose decreases by reducing the number of projections acquired during a single rotation in CT scan instead of reducing mAs. However, this is not easy to obtain on a commercial scanner used in clinical setting modality. Museyko *et al.* (104) conducted a study on 26 cadavers: authors reported that lowering tube potential from 120 to 80 or 90 kV may be considered as an important option to reduce radiation exposure. Moreover, they simulated a reduced mAs protocol (from 150 to 100 mAs) finding that also tube load did not affect the results for bone integral volume or BMD. An interesting topic is the possibility to correlate the HU measured in specific bone segments to DXA measures in order to identify osteoporosis by using CT scans performed for other clinical indications (105,106) and without an additional dose to patient being needed. Finally, Wu *et al.* (107) investigated the opportunity of dose reduction using iterative reconstruction. They reported a phantom study in which BMD has been evaluated for different combination of mAs and iterative reconstruction techniques. The same Authors demonstrated that, under different mAs and level of iterative reconstruction, the dose decreased significantly without affecting BMD accuracy. In *Table 5* a comparison among doses involved in different BCA procedures is reported.

Cancer risk

The radiation dose from some CT (>10 mSv) falls within the range where a direct evidence for increase of cancer risk exists. In general, a 5% excess risk of death from cancer per Sv of effective dose is estimated (108,109). *Table 6* reports the excess risk of death for radio-induced cancer from a

Table 6 Excess risk of death for radio-induced cancer from typical effective dose used in medical imaging examinations and comparison of medical imaging and background dose. Adapted from (75)

Examination	Effective dose (mSv)	Excess risk of death from cancer (%)	Time to accumulate comparable natural background dose [§]
Quantitative CT	3	<0.02	1 year
DXA	0.075	<0.001	9 days
DXA low dose	0.001	<0.00001	<1 day

[§], about 3 mSv/year. CT, computed tomography; DXA, dual energy X-ray absorptiometry.

Table 7 ICNIRP limits of exposure to static magnetic fields. Adapted from (112)

Exposure characteristic	Magnetic flux density
Occupational	
Exposure of head and trunk	2 T
Exposure of limbs	8 T
General public	
Exposure of any part of the body	400 mT

ICNIRP, International Commission on Non-Ionizing Radiation Protection.

typical effective dose used in medical imaging examinations: the risk is calculated assuming a 5% excess risk of death from radiation-induced cancer per Sv of radiation and applying the LNT model.

Concerning the issue of risk communication to patients, a simple way to communicate radiological risk could be to compare doses from medical exposure with background doses (as in *Table 6*) or with the risk associated with normal daily activities. For example, doses between 0.1 and 1 mSv relate to an increased risk of death from cancer equal to the risk associated with a 4,500-mile flight; doses between 1 and 10 mSv with a 2,000-mile trip (28). Berrington De Gonzalez *et al.* (110) developed a tool to estimate the lifetime risk of cancer incidence from exposure to IR for doses below 1 Gy: it is an online calculator called Rad RAT, based on risk models of the National Academies of Sciences' BEIR VII Committee and US National Cancer Institute (111).

MRI recommendations

Protection for SMF

Protection against SMF effects previously described (nausea, vertigo, etc.) can be realized as indicated in DE 35/2013

and International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines. *Table 7* shows the limits of exposure of SMFs as indicated by ICNIRP (112) and transposed in DE 35/2013, for workers and the public.

For patients undergoing MRI procedures ICNIRP provides specific recommendations such as:

- ❖ To use the normal operating mode in routine MR examinations;
- ❖ To move patients slowly into the magnet bore to avoid the possibility of vertigo and nausea.

Moreover, the threshold for motion-induced vertigo has been estimated to be around 1 T/s (for a time interval greater than 1 s): the effects of induced electric fields and currents can be avoided undergoing this threshold. Finally, ICNIRP suggests limit exposition at 0.5 mT (static field) in order to prevent interference with electronic medical devices implanted in patients.

Protection for LF fields

Interactions between body and external LF fields (gradients in MRI) must be checked, limiting exposure below the thresholds (with an additional preventive reduction factor) showing adverse effects; limits expressed in terms of induced internal electric field strength in V/m. Because of the complexity of measuring induced internal electric field in the body, exposure limits outside the body can be defined (reference levels): remaining below reference levels in the air means that limits in the body are not exceeded. The ICNIRP Fact Sheet (55) represents a useful summary of LF effects and relative thresholds and reference levels, defined for workers and general public exposure. For patient undergoing MRI exams, MR factories give V/m values related to gradients, but we should also consider the scan protocol in order to assess patient exposure. Frankel *et al.* confirm this need measuring GMF while varying some sequence parameters (113).

Protection for RF Fields

The effect on biological tissue for RF relates to heat and they are proportional to the radiation power in the volume exposed (SAR). To prevent whole-body heat stress and excessive localized heating, the ICNIRP recommends limits for HF exposure, expressed in terms of SAR. Moreover, the MR scanner limits are in accordance with CENELEC (European Committee for Electrotechnical Standardization) regulations (114). In normal operating mode, keeping the whole-body SAR below 2 Watt/kg over any 6 min period allows average RF exposure not to exceed given limits (33). However, peak exposure can be higher (100 W/kg for a specific sequence) and RF field will vary depending on the sequence used (113).

US recommendation

The EFSUMB Federation suggests applying the ALARA (as low as reasonably achievable) principle also when using US imaging (92). US equipment screens are able to show a Thermal Index for guiding users regarding tissue heating and a Mechanical Index for likelihood and magnitude of non-thermal effects. Users should adjust machine controls in order to keep the two indexes as low as reasonably achievable, without loss of diagnostic information. If low values cannot be achieved, we can reduce examination times as much as possible.

Discussion

Among the BCA procedures, Cruz-Jentoft *et al.* (115) and Thomas *et al.* (34) recognized CT and MRI as the gold standard for the volumetric assessment of bone and body structures.

DXA is mainly used for BMD measurements (61), exposes patients to minimal radiation and has lower costs than CT and MRI. Because of this, DXA represents a valid alternative method to distinguish fat, bone mineral and LTs (116,117). As for DXA, we noticed an evident variability among different equipment, due to technologies and clinical question to investigate and a strong correlation between patient dose and device and/or type of exam. Nevertheless, effective doses remain below 0.1 mSv.

As far as MRI procedures are concerned, only a few studies report the complexity of interactions of magnetic fields and effects on biological tissue. To date, we know that there is no evidence for adverse effects of exposure to SMFs used in MRI. As for RF fields, current consensus is that no

clear link exists between MRI or associated magnetic and pulsed RF fields and subsequent health risks. The authors agree with Hill *et al.* about the conclusion reported in their study (45): “*Although MRI imaging is generally considered to be safe compared with imaging technology using ionizing radiation, there is increased concern about the potential long-term health effects of exposure, especially with the push to higher static fields along with stronger and faster switching fields. Although IARC (International Agency for Research on Cancer) did not find clear evidence that SMF are carcinogenic, the data are limited, underpowered, or suffer methodological weakness (118). Both IARC and the recent SCENIHR report suggest the need for a large, carefully designed epidemiology study*”. Finally, the authors agree with Frankel *et al.* (33) about the fact that interaction mechanism between EMF and biological tissue are not yet clear, especially regarding weak fields and non-thermal effects. Moreover, metric as SAR (for RF exposure) and induced electric field (for gradients exposure) may not be sufficient to study other effects (i.e., not heating or sensory effects or neuroexcitation).

US procedures are free-radiation safe methods to measure BCA.

As far as CT procedures are concerned, the main advantage in using them is that CT is the only modality along with MRI allowing a volumetric assessment of bone and body structures, whilst its main limitation is the IR exposure. Keeping the radiation dose as low as reasonably achievable and applying systematically the justification principle remains the most important strategy to reduce this potential risk. Recent literature investigated also the possibility to use CT scan performed for other clinical indications than BCA as an opportunistic screening method. Moreover, different technological solutions have been introduced to reduce dose in CT such as advanced AEC techniques working on tube current modulation more sensitive photon-counting detector that improve dose and image quality, and iterative reconstruction algorithm for routine clinical practice.

Patients involved in IR medical procedures could incur an excess of cancer risk over the time. The effective dose is the physical quantity recommended by ICRP to assess health risks linked to low doses. Because the effective dose refers to a standard size adult, we can use it only to assess a general level of radiation risk, not the individual risk involved in each diagnostic exposure. In any case, the individual effective dose and relative risk assessment required the advice of a medical physicist.

The LNT model remains the best and more conservative

model correlating the radio-induced cancer risk to the dose. In general, the excess risk of death from cancer per Sievert is 5%, whereas natural incidence of cancer mortality is around 25%. In *Table 1* we calculated the excess risk of death from cancer for different X-ray procedures, showing that the numbers of this risk are very low. Moreover, patients undergoing BCA procedures for Osteoporosis or Sarcopenia are middle-high aged with a consequent reduction of a long-term likelihood of radio-induced cancer.

An important issue is how to communicate risk to patient: in this paper we suggest the comparison between exam dose and time to receive the same dose from natural background.

We conclude sharing the recent position statement of American Association of Medical Physicists (119): “*At the present time, epidemiological evidence supporting increased cancer incidence or mortality from radiation doses below 100 mSv is inconclusive. As diagnostic imaging doses are typically much lower than 100 mSv, when such exposures are medically appropriate, the anticipated benefits to the patient are highly likely to outweigh any small potential risks. Given the lack of scientific consensus about potential risks from low doses of radiation, predictions of hypothetical cancer incidence and mortality from the use of diagnostic imaging are highly speculative. The AAPM, and other radiation protection organizations, specifically discourages these predictions of hypothetical harm. Such predictions can lead to sensationalistic stories in the public media. This may lead some patients to fear or refuse safe and appropriate medical imaging, to the detriment of the patient. Medical physicists continuously strive to improve medical imaging by optimizing radiation doses while ensuring that the needed level of image quality is obtained, thereby contributing to the widely recognized benefits of medical imaging.*”

Despite demonstrated benefits, the scientific evidence that a “one track action” (i.e., a single track generated from the passage of a radiation) could cause irreversible DNA damage cannot be neglected, even when exposing to low-dose radiation.

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