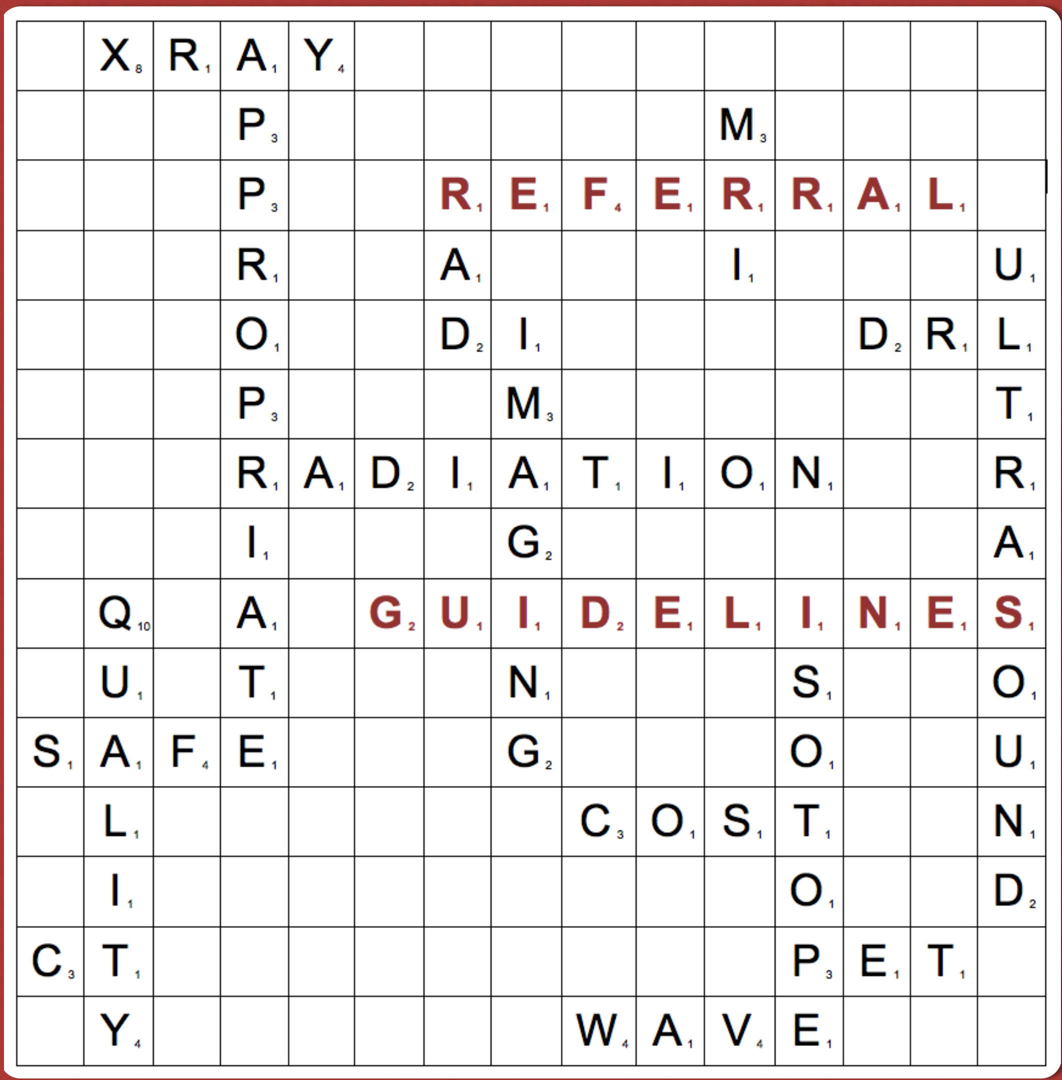
REFERRAL GUIDELINES

FOR DIAGNOSTIC IMAGING



INTERNATIONAL RADIOLOGY QUALITY NETWORK

Referral Guidelines

For Diagnostic Imaging

A Supporting Tool for Health Care Professionals

in the Selection of Appropriate Procedures

Draft Version 2.0 for Pilot Testing and User Feedback

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A Global Referral Guidelines Project

The World Health Organization (WHO) launched a Global Initiative on Radiation Safety in Healthcare Settings in 2008 (WHO 2008). The International Radiology Quality Network (IRQN) established a Referral Guidelines Working Group in 2009 (IRQN 2013). Several organizations have developed guidelines for the selection of diagnostic imaging procedures, but these guidelines are currently unavailable in many countries; and even when available, they are not yet well integrated into daily practice. To address these challenges, the 34 participants from 19 countries who attended a Global Initiative consultancy on "Referral Guidelines for Appropriate Use of Radiation Imaging" in March 2010 have agreed to undertake a referral guidelines project (Project).

The Project aims to promote safe and appropriate selection of diagnostic imaging, and to ensure these procedures are justified and indicated by providing a practical guidance tool and supporting its implementation. The optimization of imaging data and radiation protection is the next step after a procedure is selected and is outside the scope of the Project. These efforts will contribute to the prevention of unnecessary imaging procedures and their inherent risks and will facilitate a more cost-effective allocation of health resources. The Project scope includes the development, pilot, publication, distribution, implementation and evaluation of referral guidelines for diagnostic imaging, taking into account the requirements of the WHO Guidelines Review Committee. It is recognized that a regular update of these guidelines is an important and integral part of such a project.

Members of the Project Core Group and Special Interest Groups (refer to Section III) reviewed the published evidence-based guidelines and identified a set of clinical conditions, which share the same recommendations for appropriate imaging. Following incorporation of the feedback from an initial round of stakeholder consultation, a revised draft is ready for pilot testing. The Project aims to pilot these guidelines in different settings and regions. The pilot exercise will identify the means to enhance their use in practice and to measure impact.

The Project team looks forward to working with all stakeholders to achieve a common goal by improving quality, safety and appropriate use of diagnostic imaging. Safe, quality and cost-effective use of diagnostic imaging is a key building block of good health systems. Organizations and agencies lead this charge by promoting awareness and providing practical tools. These actions together with a commitment from practitioners to change and improve practice will significantly contribute to health system strengthening through a safer and more appropriate use of diagnostic imaging.

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Preface

These referral guidelines are prepared to assist all health professionals who refer patients for and provide services in diagnostic imaging and interventional radiology, including newly qualified and experienced practitioners, nurses and other health professionals, in different practice settings. These guidelines are also useful educational tools for undergraduates in medical schools.

By referring a patient for an imaging or imaging-guided interventional procedure, a referrer / prescriber is requesting a specialist opinion to assist in the clinical management of the patient. It is therefore important for the referrer to provide the imaging specialist with all the relevant information to ensure a proper evaluation of the appropriateness of the referral, and to tailor the protocol to optimize imaging data and radiation protection. When implemented in practice, this interaction between the referrer and the imaging specialist will facilitate a more rational selection and use of imaging. Although a dialogue between the referrer and the imaging specialist is always advisable, such discussion is particularly important for a patient requiring multiple or complex procedures, those procedures for conditions that are not included in these guidelines or those procedures associated with high radiation exposures.

Acknowledgement

This publication consists of three sections. Section I deals with the basic principles of diagnostic imaging and good medical practice, biological effects of diagnostic imaging and radiation protection. The material is sourced from a range of publications (CAR 2012, DOH WA 2013, EC 2000, IAEA 2011, IAEA 2013, ICRP 2007b, Lau and Ng 2014, RANZCR 2001). Section II provides a range of referral guidelines for selected conditions, based on common recommendations from the American College of Radiology, the Department of Health, Western Australia, and the Royal College of Radiologists (ACR 2013a, DOH WA 2013, RCR 2011). Section III documents the references, and includes a list of abbreviations and the Project participants.

Section I

Diagnostic Imaging: a Clinical Perspective

Modern medicine is practised with an understanding of the disease processes based on scientific evidence. The care and management of patients are guided by the diagnosis of the underlying diseases. With the advances in the last three decades, diagnostic imaging has evolved and played an important role in reaching these diagnoses. Diagnostic imaging specialists and interventional radiologists are contributing members of the clinical teams and work towards the improvement of care and management of many patients.

A diagnostic imaging procedure is not required for many conditions. In some instances, a procedure is requested which will not alter patient care or add confidence to the diagnosis thus incurring unnecessary cost and irradiation. A diagnostic imaging procedure is indicated when the management of a patient depends on the findings of the procedure. It should be noted that it is not obligatory in all clinical conditions for a definitive diagnosis to be made. Further, it is important to be aware of the local treatment options prior to imaging to ensure appropriate care is available following a diagnosis. Similarly, interventional radiology is used if it provides an equal or better outcome than alternative techniques with lower morbidity and mortality. Therefore, before any diagnostic imaging procedure is requested, the question should always be asked as to how the results will influence patient management and care. Of particular importance must be an assessment of the consequence of failing to diagnose a treatable disorder.

Prior to requesting a procedure, it is useful to determine if the required information is already available from recent procedures and if the relevant clinical, laboratory, diagnostic imaging and treatment information are provided. For those procedures resulting in significant radiation exposure, e.g. CT scanning, complex diagnostic imaging and some interventional procedures, individual justification by the imaging specialist is particularly important and should take account of all the available information. When indicated and available, alternative diagnostic imaging procedures, which do not use ionizing radiation, e.g. ultrasound or MRI; and alternative imaging guidance for interventional procedures, e.g. ultrasound, should be chosen first, especially in children. Cost, local expertise, and resources are further considerations.

Few diagnostic imaging procedures are absolutely specific and absolutely sensitive in making a diagnosis. A procedure with a high specificity has few false positives – i.e. there is a low likelihood of the procedure suggesting a diagnosis, or disease process, which is in fact not present. A procedure with a high sensitivity has few false negatives – i.e. there is a low likelihood of the procedure not suggesting a diagnosis or disease process, which is in fact present. Some procedures are highly specific, but not very sensitive. These procedures have few false positives, so are valuable when positive, but less value when negative. Other procedures are not highly specific, but very sensitive. Such procedures have few false negative, so are of more value when negative than when positive.

Of importance, when considering sensitivity and specificity, is the disease prevalence in the population. Even if a procedure is relatively specific, and has few false positives, if the prevalence of the disease process is very low, the likelihood will still be that a positive result of the procedure is a false positive rather than a true positive. Conversely, even if a particular procedure is very sensitive and has few false negatives, if the prevalence of the disease process is high, then a negative result of the procedure will likely be a false negative rather than a true negative.

Other factors that need to be borne in mind, with all diagnostic imaging and interventional radiology procedures, are the possibility of adverse effects related to the procedures and the cost of the procedure. Adverse effects could be due to the use of ionizing radiation, contrast media, or complications from interventional procedures. Costs may be both direct and indirect. Table 1 summarizes the key questions that referrers should consider before requesting a procedure, to prevent an unnecessary use of radiation. (Adapted from RCR 2007)

Questions to be answered	To prevent an unnecessary use of procedure and radiation due to:
Has this procedure been done already?	*Repeating procedures that have already been done*
Does the patient need it?	*Undertaking procedures when results are unlikely to affect patient management*
Does the patient need it NOW?	*Investigating too early or too often i.e. before the disease could have progressed or resolved or before the results could influence treatment*
Is this the best[1] procedure?	*Selecting the wrong procedure*
Have I clearly explained the clinical problem and the indication to the imaging specialist?	*Failing to provide appropriate clinical information and questions that the procedure should answer*
Are all the investigations I am requesting necessary?	*Over-investigating*

Table 1: Questions to be considered before requesting a procedure. [1]"Best" is used as "appropriate", it refers not only to sensitivity and specificity, but also the 4 'A's: availability, affordability, ability of the imaging specialist, and absence or presence of ionizing radiation, e.g. the use of US or MRI instead of CT.

If there is doubt as to whether a procedure is required or which procedure is best, an imaging specialist should be consulted. Indeed, imaging specialists in diagnostic imaging facilities would be pleased to discuss procedures with referrers. In hospital settings, regular clinico-radiological meetings provide an excellent opportunity for such discussions and are considered good medical practice.

No procedure should ever be requested without consideration of the above factors. Nor should a procedure ever be requested in lieu of a thorough clinical assessment or as a means of placating a difficult patient. Users of diagnostic imaging and interventional procedures have a duty of care to ensure these procedures are clinically justified and will bring more benefit than harm to their patients.

Diagnostic Imaging: a Health Care System Perspective

There has been an increasing use of diagnostic imaging in recent years. About 3.6 billion diagnostic x-ray imaging procedures and 33 million diagnostic nuclear medicine procedures are performed around the world each year. The estimated global annual collective effective dose from diagnostic medical and dental radiological procedures has increased by 75% from 2000 to 2008 (UNSCEAR 2010). Indeed, the average annual collective dose has risen from 2,300,000 to 4,000,000 man Sv and in the same period the annual per caput effective dose averaged across the world's population has risen from 0.4 mSv to 0.62 mSv. Many of these procedures have led to improvements in the diagnosis and treatment of numerous conditions and provided great benefits to patients. However, inappropriate use of radiation in health care may result in unnecessary radiation exposure and its associated health risks such as cancer. This may impact on the cost-effective allocation of health care resources and could lead to a waste of the finite resources. In some settings, the skyrocketing cost of health care and diagnostic imaging is simply unsustainable.

Good health services deliver safe and effective health interventions to those who need them, when and where they are required, with minimum waste of resources. "Overuse" is requesting procedures that will unlikely improve patient outcome. The increasing use of radiation in diagnostic imaging cannot be considered as overuse "per se". It is either appropriate or inappropriate. For example, expanded applications and aging populations are understandable reasons for an increase in demand. A knowledge gap, inadequate clinical assessment or the practice of defensive medicine could lead to inappropriate use. Inappropriate use of diagnostic imaging will lead to unnecessary or unintended radiation exposures and users of these procedures need education and guidance on appropriate use, radiation safety and radiation protection.

Most medical students and health professionals have a low awareness of radiation safety, radiation doses and potential health risks and are not well informed on the existing guidance on an appropriate use of diagnostic imaging. There is a need to improve their education and training in order to minimize the unnecessary use of procedures and radiation exposures. This could be achieved by strengthening undergraduate teaching and postgraduate Continuing Professional Development programs by including information on radiation safety.

As to be discussed in the following section, procedure justification and optimization are the two key principles of radiological protection in health care, which are implicit in the notion of good medical practice. Providing guidance on procedure justification, optimization of imaging data and radiation protection, as well as error prevention will contribute to an overall improvement in radiation safety culture in medical practice.

Referral guidelines for diagnostic imaging are intended to assist all health professionals who are eligible to refer patients for these procedures. They are reliable resources to update practitioners and to guide them towards *good practice. At both undergraduate and postgraduate levels, referral guidelines should be made available and used to guide an appropriate selection of diagnostic imaging procedures. The use of referral guidelines in undergraduate teaching is encouraged. In medical schools, it is useful for the faculties to emphasize and the students to understand that the practice of medicine differs between academic and community settings. Care at tertiary referral centers requires high-tech procedures more than community practices because the disease complexity, variety and prevalence are very different.*

It is important to recognize that diagnostic imaging is not a timesaving substitute for a careful and complete clinical history and examination. In fact, in many situations, a patient's management does not require further investigation. When diagnostic imaging is indicated, the first consideration is the type of information required, i.e. structure versus function. Frequently only one procedure is required, even though a full range of modalities is available, all of which are capable of providing similar information. In such situations, cost, availability, expertise, side effects, sensitivity, specificity and accuracy all play a part in the selection of the most appropriate imaging procedure.

In countries offering a national health scheme, diagnostic imaging expenditure forms part of the government's budget outlay. In others, the patients pay for imaging procedures directly. Universal health insurance is rare outside developed countries. Even with private insurance, the use of more expensive imaging procedures could be limited. Referrers should be aware of the cumulative cost of imaging procedures to patients, whether covered by insurance or not, and be informed of the most cost-effective means of diagnosing a particular disease.

Modern technology such as CT, MRI, PET, CT/PET is relatively expensive but these procedures frequently enable a diagnosis to be made on an outpatient basis, thus avoiding costly hospitalization. Sometimes more than one procedure is required. The appropriate sequencing of multiple procedures requires carefully consideration to ensure that a most direct path is chosen. With complex clinical problems, consultation with the imaging specialist is essential.

Referral Guidelines

Clinical guidelines are systematically developed statements to assist referrers and patients to make decisions about the appropriate care for specific conditions. As the term implies, guidelines are not absolute rules and are not rigid constraints on clinical practice. They are used to promote good medicine by matching the recommendations to the needs of an individual patient.

Evidence-based referral guidelines in a user-friendly format, are invaluable decision-aiding tools to support justification by assisting referrers towards better, safer, and more appropriate use of diagnostic imaging and interventional radiology. In 1990, the WHO published a report on the 'Effective choices for diagnostic imaging in clinical practice' (WHO 1990). Over the last two decades, referral guidelines were initially developed by the American College of Radiologists (ACR), Royal Australian and New Zealand College of Radiologists (RANZCR), and Royal College of Radiology (RCR). Based on the RCR guidelines, the European Commission (EC) published referral guidelines to be applied in the EU region. European countries translated the EC guidelines, and some of them adapted the guidelines to local conditions with the contribution of national professional bodies. The Argentine Society of Radiology (SAR) adapted the EC guidelines. Referral guidelines are now available in different regions of the world, e.g. Argentina, Australia, Austria, Canada, France, Germany, Hong Kong, Japan, UK and USA etc. Despite the on-line availability of referral guidelines, which were mainly published by professional organizations from developed countries, their use in developing countries may be limited and inappropriate due to differing disease prevalence, equipment access, and cost. Even in those countries where guidelines exist, they are not yet well integrated into daily medical practice.

Three basic formats are used:

1. *For a condition, the possible procedures are listed and each procedure is provided with an appropriateness score in a table format, supplemented by text. This is the approach used by the American College of Radiology in its publication 'Appropriateness Criteria' (http://www.acr.org/secondarymainmenucategories/quality_safety/app_criteria.aspx).*
2. *For a condition, the possible procedures are listed with their recommended roles provided in a table. These roles are classified as: indicated, special investigation, not indicated initially, not indicated routinely and not indicated. This is the format used by the Royal College of Radiologists in 'Making the Best Use of a Department of Clinical Radiology: Guidelines for Doctors' and the Canadian Association of Radiologists in 'Diagnostic Imaging Referral Guidelines'. This format was subsequently adopted by a number of European countries.*
3. *For a condition, the approach and choice of procedures are provided in an algorithm format. This is used by the Royal Australian and New Zealand College of Radiologists in 'Imaging Guidelines' and the Royal Perth Hospital / Western Australia Department of Health in 'Diagnostic Imaging Pathways'.*

(http://www.imagingpathways.health.wa.gov.au/includes/DIPMenu/llpain/chart.html).

The typical radiation dose for each procedure is provided, usually by comparing with the equivalent number of chest x-rays and/or the equivalent period of exposure to natural background. The guidelines are published in a range of media: printed hard copy, CD, web-based, adapted for mobile devices or integrated into radiology information systems. The incorporation of guidelines into clinical decision support systems, i.e. computerized physician order entry (CPOE) will improve their use in daily practice.

Clinical Data in Referrals

The referral for a diagnostic imaging procedure is a request for an opinion from an imaging specialist. The outcome of this referral is usually presented as a report to assist in the patient's management. A request or referral letter should be completed accurately and legibly to avoid any misinterpretation. The reasons for the referral should be clearly stated and sufficient clinical details should be supplied to enable the imaging specialist to understand the particular diagnostic or clinical problems to be resolved by the procedure.

The information provided in a referral for diagnostic imaging does not need to be lengthy, but all relevant data must be given to ensure best patient care. This is particularly important if the patient is unable to communicate or if there is a language barrier.

As mentioned in a previous section, justification and optimization are the two key pillars of radiation protection of patients, and are closely linked. For example, to optimize imaging data and radiation protection, it is essential to know what the clinical question is and how the procedure could assist in the patient's management. Methods for dose reduction can then be applied and protocols can be tailored according to the clinical condition and patient size (which is critical in pediatric imaging), to achieve diagnostic images, to provide the answer to the question raised in the request and to minimize noise to an acceptable level. Moreover, optimization may influence the risk/benefit analysis implicit in the justification of the procedure, e.g. a lower dose technique will result in a lower risk, thus increasing the net benefit.

The referrer has a key role to play in the implementation of justification of procedures and in the optimization of radiation protection and imaging data. Optimization of protection in medical exposures requires the management of the patient dose to be commensurate with the medical purpose. While optimization is implemented by the professional team performing the procedure, i.e. radiologists, medical physicists, radiographers and nuclear medicine physicians etc, the referring practitioner can contribute by providing the necessary information to the imaging team.

It is therefore essential for a referrer to provide all the relevant information so that the imaging specialist can evaluate the appropriateness of the referral if/as necessary, and tailor the protocol to optimize protection. When properly addressed and managed, this interaction between a referrer and imaging specialist promotes a more rational use of imaging.

Personal Details

A correct entry of the patient's name, address, date of birth, and reference number will ensure accurate image labeling, archiving and retrieval of previous procedures and records.

Procedure

The side and the body region to be examined and the modality and the type of procedure to be used must be clearly stated. Ambiguous terms such as 'abdominal scan' lead to confusion and must not be used.

Clinical Information

Relevant clinical information is extremely important, both in tailoring of the procedure to obtain the maximal information with minimum exposure and in image interpretation. As a minimum, the information should include the:

- *Height and weight, i.e. to facilitate procedure optimization;*
- *Relevant history, e.g. previous surgery, cancer, major trauma, renal impairment, communicable disease, immune status, and appropriate allergies or risks;*
- *Results of previous relevant diagnostic imaging and other investigations;*
- *Major signs and symptoms and their duration, e.g. the site of maximum tenderness following trauma, may indicate the need for special views;*
- *Main objective of the procedure, e.g. the characterization of a suspected liver haemangioma requires a protocol different from a standard abdominal CT; and*
- *Possibility of pregnancy.*

Allergies and Contraindications

Any previous reaction to contrast media must be prominently recorded in the request. The nature of the reaction and any treatment required should be described as these are useful in distinguishing between a true allergic reaction and other events such as transitory nausea. Risk factors such as severe asthma and predisposition to allergy should be noted. Prior to referring a patient for MRI, the presence of contraindications such as cardiac pacemakers, ferromagnetic intracranial aneurysm clips, cochlear implants, metallic foreign bodies and stainless steel stents should be excluded by using a detailed checklist.

Referrals

All referrals should be signed and dated, and include the referrer's appropriate contact details. If the result of the investigation is urgently needed, the referrer should indicate this on the request, so that the procedure is prioritized accordingly. An effective communication channel is important to enable discussion between the referrer and imaging specialist if and when necessary to clarify the urgency of the request, indication and imaging strategy; or to deliver urgent or unexpected results. The imaging specialist should have a system in place to inform the referrer of urgent, unexpected or significant abnormalities to ensure prompt intervention.

Previous Records

Relevant previous imaging records and / or reports should be available to assist in the planning and reporting of a procedure, particularly if any comment on progress is required. If patients are storing their own imaging records, referrers must encourage them to maintain these records carefully and bring them to the next diagnostic imaging procedure.

Diagnostic Imaging Modalities

Computed Radiography (CR) and Digital Radiography (DR)

Basic Principles

Computed Radiography (CR) and Direct Radiography (DR) are digital imaging techniques, which generate 2-D images and use similar equipment to conventional radiography. In CR, an imaging plate (IP) made of photostimulable phosphor housed in a special cassette is used instead of a film / screen combination. CR systems process optical signals based on 'photostimulated luminescence'. The cassette with the IP is placed under the region to be examined when the x-ray exposure is made. A laser scanner (CR reader) reads and digitizes the image. This digital image can be further enhanced by image-processing software.

DR captures the image directly onto a flat panel detector without the use of a cassette. There are many different types of DR detectors: each has its own merits and may be applied to certain imaging requirements based on these attributes. The major types of detectors include Thin-Film-Transistor (TFT) made of Amorphous Selenium (direct DR) and Amorphous Silicon coated with Cesium Iodide (indirect DR). DR detector immediately reads the transmitted x-rays signal passing through the patient to the detector.

As technology advances, the distinction between CR and DR is less relevant. Sometimes, a CR based cassette-less system can be called a DR system. Digital Radiography has become a common terminology for this form of two-dimensional digital imaging. The advantages of DR over conventional radiography are its large dynamic range, digital platform, portability and post-processing capability.

Diagnostic Information

- *High resolution images in two-dimensions; and*
- *Image processing enables contrast, density and other adjustments to optimize diagnostic data.*

Indications

For specific indications, please refer to the individual sections. In general, CR and DR are useful for:

- *Imaging in trauma;*
- *Imaging of bony skull, spines and extremities;*
- *Imaging of chest and abdominal conditions;*
- *Monitoring progress of pathologic conditions; and*
- *Mammography.*

Contra-indications

- *Ionizing radiation exposure undesirable, e.g. pregnancy; and*
- *Patients who are unable to remain stationary.*

Advantages

- *Readily accessible, progressively replacing conventional radiography;*
- *Relatively non-invasive;*
- *Fast;*
- *Standardized technique with post processing functionality;*
- *Reduces repeats due to poor exposures;*
- *No film or chemistry required;*
- *Reduces film storage;*
- *Enables electronic health record keeping through RIS system or PACS when available;*
- *Multiple image viewing options; and*
- *Enables transmission to other locations for reporting or second opinion.*

Disadvantages

- *Uses ionizing radiation;*
- *Possible increase in exposure due to 'exposure creep';*
- *Variation in exposure factors could lead to gross over exposures;*
- *Basic CR units allow the use of only one size of cassette;*
- *CR reader very susceptible to humidity; and*
- *Expensive imaging plates, detectors and monitors.*

Patient Preparation

Fasting is required if intravenous contrast is needed, e.g. Intravenous Pyelography (IVP).

Ultrasound

Basic Principles

Ultrasonography refers to the use of sound waves i.e. ultrasound (US) for diagnostic imaging purposes. A pulse of US is transmitted into the body via a small probe, i.e. a transducer. Depending on the tissue characteristics and the interfaces between tissues, this beam will be partially reflected, absorbed or transmitted. The image generated is based on the reflected US beam received by this transducer.

Doppler ultrasound depends on the alteration of the frequency of the ultrasound beam when reflected by moving blood cells. The blood flow direction and velocity can be calculated and can provide an assessment of *patency or narrowing of vessels. Colour Doppler ultrasound colour-codes blood flow based on frequency and flow direction data and enables a better graphic display and assessment. Colour flow imaging is based on echo signal amplitude, rather than frequency. This allows a better assessment in slower flow situations than conventional Doppler, and is less dependent on obtaining a satisfactory angle of insonation.*

In the last two decades, ultrasound equipment and expertise have advanced and the applications have widened. These trends are to be welcomed because ultrasound does not employ ionizing radiation.

Ultrasound contrast agents are useful in selected patients, particularly in the assessment of vessels where there is slower flow and in the investigation of tumor vascularity. Other technological advances in ultrasound include harmonic imaging and 3-D imaging.

Diagnostic Information

Dynamic anatomical display is available in any plane and at any angle, with good resolution. Ultrasound is excellent in distinguishing solid from cystic masses. Cardiovascular and fetal motions are shown in real time. Doppler is useful for the assessment of blood flow and severity of vascular stenosis without the use of intravascular contrast media.

Indications

For specific indications, please refer to the individual sections. In general, ultrasound is useful for:

- *Obstetric imaging;*
- *Brain imaging in neonates;*
- *Abdominal, pelvic, musculoskeletal, scrotal, thyroid and breast imaging;*
- *Cardiac imaging (echocardiography);*
- *Vascular imaging;*
- *Endoluminal imaging: transrectal prostate ultrasound, endoscopic ultrasound, and transoesophageal echocardiography (TOE); and*
- *Imaging-guided intervention: injection, fine needle aspiration, core biopsy, fluid drainage and intra-operative procedures.*

Advantages

- *Widely accessible;*
- *Non-invasive and painless;*
- *Accurate and fast;*
- *No ionizing radiation used, i.e. most suitable for pregnancy and children;*
- *Good anatomical details; and*
- *Relatively inexpensive.*

Disadvantages

- *Anatomic depictions that are not easily reproduced nor understood by most referrers; and*
- *Limited by obesity, scar, bowel gas and bone.*

Patient Preparation

No preparation is required for most ultrasound procedures. For abdominal ultrasound, fasting is required to enable adequate examination of the gallbladder, biliary tract, pancreas and other retroperitoneal structures. For pelvic ultrasound, a full bladder is necessary to act as an acoustic window for an assessment of the pelvic organs. Transvaginal ultrasound offers a more superior evaluation of the female pelvis.

Computed Tomography (CT)

Basic Principles

The basic principle underpinning CT is the same for a basic or a state-of-the-art dual energy multi-detector scanner. An x-ray tube coupled to a detector system emits a finely collimated x-ray beam as it rotates within a gantry around the patient. Depending on the tissue composition, the detectors receive a variable amount of the x-ray beam that has passed through the body. This data is reconstructed into an image following the application of mathematical algorithms. Intravenous contrast media is used to outline vascular structures or to assess the enhancement characteristics of pathological processes. Bowel contrast may also be used for abdominal imaging.

Helical CT (or spiral CT) has almost completely replaced non-helical CT, and allows the x-ray tube to rotate continuously as the body is moved through the gantry. The detectors thus record a larger continuous volume of data for a body region rather than data separated into single slices. These data can be reconstructed into axial, sagittal and coronal images as well as other reconstructions with excellent image quality. The information can be manipulated based on the tissue attenuation to enable structures such as bones to be viewed without adjacent soft tissues or to provide 3D angiographic displays.

Helical CT enables faster scanning of a structure or organ in a single breath-hold. This feature overcomes the problem of mis-registration, i.e. small lesions falling between the individual slices, when single slice breath-hold scans are obtained. This is important when imaging small lesions in the liver, lung, adrenals etc. Furthermore, rapid helical CT allows a better timing of imaging during maximal intravenous contrast enhancement, which is important in CT angiography (CTA) and arterial-phase scanning. Indeed, with helical CT it is possible to obtain multiphasic images of an organ, i.e. in the arterial and venous phases of contrast enhancement as well as delayed scans, in rapid succession.

CTA offers superior anatomical resolution and has replaced conventional angiography, which is now only used as part of an interventional procedure. CTA is used to evaluate patients with suspected cerebral aneurysm, pulmonary embolism, aortic aneurysm, aortic trauma, aortic dissection, or limb ischemia.

Single slice scanners use a single row of detectors that only provides one channel of image information for every one rotation of the gantry. In multi-detector scanners, multiple rows of detectors are used allowing for registration of more than one channel of variable width per gantry rotation. The number of detector rows ranges from 2 to 320. Multi-detector CT (MDCT) scanners have faster gantry rotation allowing for much larger volumes to be imaged in a single breath-hold. MDCT enables rapid scanning, with less motion artifact, higher image resolution and a reduction in intravenous contrast media dose.

Dual energy CT is based on the information obtained by scanning with different energy levels. Coupled with software, different tissues are better differentiated. In parallel with these innovations, equipment manufacturers are improving the scanner design and reconstruction algorithms to optimize and reduce radiation dose. For example, the new generation of scanners offers a 50-80% reduction in exposure while retaining image quality.

Diagnostic Information

- *High resolution images in multiple planes;*
- *Selective display of structures based on attenuation, e.g. blood vessels, bones to be viewed without overlying soft tissues; and*
- *3-D display of images has led to new applications: CT angiography, CT cholangiography, 3-D reformation for reconstructive plastic surgery, virtual colonoscopy etc.*

Indications

For specific indications, please refer to the individual sections. In general, CT is useful for:

- *Cerebrovascular accidents;*
- *Imaging in trauma;*
- *Staging and monitoring of malignancies;*
- *Imaging of the chest and abdominal conditions;*
- *Providing pre-operative assessment of complex masses;*
- *Assessing post-operative complications; and*
- *Imaging-guided intervention: injection, fine needle aspiration, core biopsy and fluid drainage.*

Contra-indications

- *Ionizing radiation exposure undesirable, e.g. pregnancy;*
- *Barium and metallic prostheses that may degrade image quality; and*

- *Patients who are unable to remain stationary.*

These relative contra-indications require careful justification.

Advantages

- *Readily accessible;*
- *Relatively non-invasive;*
- *Accurate and fast;*
- *Standardized technique;*
- *Excellent anatomical details with a display that is widely understood by all referrers; and*
- *Not limited by obesity, scar, bowel gas or bone.*

Disadvantages

- *Uses ionizing radiation;*
- *Expensive; and*
- *Possible sensitivity to contrast media.*

Patient Preparation

Fasting is required if intravenous contrast media is needed. For abdominal and pelvic procedures, very diluted barium or iodinated oral contrast is usually given prior to scanning. Very occasionally, rectal contrast may be administered. Water or air is the alternative endoluminal contrast media used in some circumstances.

Nuclear Medicine

Basic Principles

Most nuclear medicine procedures require the intravenous administration of short-lived radioisotopes. At the site of localization within the targeted organ, the isotopes give off ionizing radiation (gamma rays), which are detected by an external imaging device (gamma camera). Nuclear medicine is a very sensitive modality, as most pathological processes will affect cell function before structural changes are evident. A CT/SPECT system consists of a CT gantry and a gamma camera; the software combines the CT and nuclear medicine images thus offering both anatomic and functional data at the same time.

Most procedures use an isotope that is either a) in its free form, e.g. pertechnetate for thyroid, salivary or Meckel's imaging; technetium or thallium for cardiac or tumor imaging; gallium for infection, inflammation or tumor imaging; b) bound to cells, e.g. red or white blood cells; or c) a chemical ligand that determines the organ of uptake. Most procedures are performed using technetium (Tc99m), which has a half-life of 6 hours, as the radioactive source. This agent has properties that are optimal for detection by a gamma camera and can be chemically bound to a wide range of substances.

Nuclear medicine demonstrates the in-situ biochemical or physiological disturbances of disease. Although some patterns of isotope distribution are characteristic for certain disease processes, most studies have low specificity and spatial resolution and may require other anatomical imaging techniques for further evaluation.

Positron Emission Tomography (PET) uses short lived, cyclotron-produced positron emitting isotopes. These are injected into the patient to provide functional information, which is imaged by a PET scanner. The most commonly used agent is fluorine-18 labeled fluorodeoxyglucose (18F-FDG). The positron emitting isotope fluorine-18 is substituted for a hydroxyl group in the glucose molecule. FDG uptake and subsequent retention is a marker of cellular glycolytic activity. Other PET radiopharmaceuticals are now available which can be used to evaluate various biological processes. Rubidium-82 is becoming standard for myocardial perfusion imaging. Combined PET-CT scanners are gradually replacing dedicated PET scanners and are becoming standard practice.

Diagnostic Information

A functional image is obtained based on the concentration and distribution of the isotopes within the target organ. The distribution of this isotopic activity passing through an organ with time can be analyzed mathematically to derive functional data such as half-clearance time, ejection fraction, and relative perfusion. Tomographic images (SPECT) can assist the localization of isotopic activity within an organ.

The higher metabolic activity of tumors and their preference for glucose as an energy substrate leads to the high sensitivity and specificity of FDG PET procedures in oncology. PET can identify small foci of viable tumors, so it offers exceptional opportunities in the staging of various cancers and in cancer follow-up, where other imaging techniques may be unable to distinguish between residual fibrotic masses and active disease. PET can provide unique data about brain metabolism and myocardial viability.

Indications

Refer to specific sections. Nuclear medicine is a very sensitive modality for most serious disorders of bone. It is helpful for the early detection of infection, metastases and active benign and malignant tumors. There is particular value in the functional data that can be provided by nuclear medicine techniques. For example, at a basic level, it can determine whether a distended renal pelvis shown by ultrasound is due to a capacious collecting system or is caused by an obstructing lesion. The same investigation can assess the percentage of overall renal function provided by each kidney. More complex studies can indicate the ejection fraction of the left ventricle or the distribution of blood flow to the cerebral cortex.

Contra-indications

- *Residual barium can lead to artifacts; and*
- *Pregnancy.*

Advantages

- *Readily accessible;*
- *Standardized technique; and*
- *Functional changes may precede alterations in structure.*

Disadvantages

- *Uses ionizing radiation;*
- *Poor spatial resolution; and*
- *Many procedures are sensitive but not specific.*

Patient Preparation

Fasting may be required for some procedures.

Magnetic Resonance Imaging (MRI)

Basic Principles

Magnetic resonance imaging uses strong magnetic fields and radiofrequency (RF) pulses to generate sectional images of the body in any plane. The image depends on the density of protons or water molecules within the tissue and other physical characteristics of the tissue. Hydrogen nuclei have a non-zero magnetic moment. When the tissue is placed within the scanner, the magnetic moments of the protons align themselves with the main magnetic field of the scanner. After the hydrogen protons are aligned in a known direction, a RF pulse is applied which causes a number of hydrogen protons to flip or absorb energy. After the RF pulse is switched off, the protons gradually return to their previous positions. In this process, the protons release energy as RF signals. It is these signals that are used to reconstruct the MRI images.

Moving protons within blood vessels can be displayed without the background soft tissues as a magnetic resonance angiogram (MRA). Improvements in software have resulted in MRA having comparable spatial resolution to CTA. MRA is used to evaluate cerebral and neck arteries, thoracic and abdominal aorta, renal and limb arteries for stenosis, occlusion or aneurysm. Functional imaging allows non-invasive mapping of areas such as the sensorimotor and visual cortices. Automated perfusion imaging and chemical shift spectroscopy provide further valuable information regarding blood flow and metabolism in stroke, epilepsy, neuropsychiatric disorders and brain radionecrosis. Modern scanners are able to image diffusion within tissues and capable of consistently demonstrating cerebral infarcts less than 6 hours old.

Diagnostic Information

MRI images are the result of the difference in signal intensities between tissues such as CSF, air, bone, muscle, and brain. This in turn is determined by many different factors including proton density within the different tissues, flow effects, paramagnetic effects, pulse sequence used and the presence or absence of injected contrast media within the tissues. In general, MR provides much better tissue differentiation than CT through a variety of processes that are very helpful in characterizing blood, fat, or iron.

MRI usually provides more information than CT about intracranial, head and neck, spinal, and musculoskeletal disorders because of its superior contrast sensitivity, which enables anatomy and pathological processes to be shown with greater clarity. Although CT offers good anatomic depiction, MRI has the advantage of better inherent soft tissue discrimination, i.e. tissue contrast differences. For this reason, intravenous contrast media are needed less often with MRI than it is with CT.

Indications

Refer to specific section. MRI is widely used for the:

- *Assessment of neurological disorders, including brain and spinal contents;*
- *Functional imaging of the brain;*
- *Assessment of musculoskeletal disorders;*
- *Staging of malignancies: head and neck, prostate, gynecological and pelvic;*
- *Assessment of cardiac, aortic and vascular disorders;*
- *Assessment of abdominal conditions, e.g. liver, biliary tree (magnetic resonance cholangiopancreatography MRCP), pancreas, kidneys, anal fistula, MR enterography;*
- *Breast lesions; and*
- *MR-guided interventional procedures.*

Contra-indications

- *Cardiac pacemakers, ferromagnetic intracranial aneurysm clips, cochlear implants, and epidural electrodes;*
- *Metallic foreign bodies in the eyes;*
- *Intraarterial or intravenous stainless steel stents inserted in the past 6 weeks; and*
- *Relative contra-indications: first trimester of pregnancy, claustrophobia and marked obesity, because girth and weight limits vary between scanners.*

Advantages

- *Relatively non-invasive and painless;*
- *Accurate and relatively fast;*
- *Standardized technique;*

- *No ionizing radiation used, i.e. most suitable for pregnancy and children;*
- *Excellent anatomical details; and*
- *High sensitivity to a wide range of conditions.*

Disadvantages

- *Expensive;*
- *Limited by metallic medical devices and claustrophobia; and*
- *Less availability and less widespread expertise.*

Patient Preparation

Fasting is required if intravenous contrast is needed. MRI scanners will erase the data stored in cards equipped with magnetic strips, e.g. credit cards.

Mammography

Basic Principles

High contrast images with excellent soft tissue detail have been developed for mammography. Mammography equipment has many dedicated features to maximize soft tissue detail and is used with specialized recording systems. Digital mammography acquires digital x-ray information using specialized detectors instead of film. The digital images are reviewed on a computer workstation with high-resolution monitors.

Diagnostic Information

Masses, calcifications and distortions of breast architecture are shown by mammography. Ultrasound is used to further evaluate suspicious areas or lymphadenopathy and to guide biopsies if indicated. Difficulties exist with dense breasts, where small lesions may be obscured.

Indications

The primary aim of mammography is the early detection of breast cancer. It is also used to assess breast symptoms and palpable abnormalities.

Screening Mammography

Breast screening is a method of detecting breast cancer at an early stage. Mammography is used to detect changes, which may indicate cancers and are too small to be felt by physical examination. The WHO International Agency for Research on Cancer (IARC) working group evaluated the available evidence on breast cancer screening and determined that there is a 35% reduction in mortality from breast cancer among screened women aged 50 - 69 years old (IARC 2002).

Diagnostic Mammography

Mammography is indicated to:

- *Confirm suspected cancer and to detect pre-clinical disease in the other breast;*
- *Follow-up of a patient with a past or family history of breast cancer;*
- *Assess large and nodular breasts, which are difficult to examine clinically; or*
- *Evaluate those patients with symptoms or signs suggestive of benign disease.*

Contra-indications

- *Mammography is rarely necessary in patients < 25 years and occasionally necessary in those < 35 years. In these young patients consider ultrasound or MRI assessment.*

Advantages

- *Generally accessible;*
- *High sensitivity in the pre-clinical diagnosis of cancer; and*
- *Adjunct to clinical assessment.*

Disadvantages

- *False negative rate for mammography is 7-10%;*
- *False positives resulting in unnecessary biopsies; and*
- *Relative radiation risk. This is of decreasing concern due to technological improvements leading to a lower dose for mammography. Furthermore, the benefits of early cancer detection allowing prompt treatment, including conservation surgery, far outweigh the theoretical risk.*

Warning

- *Interval cancers*

Screening programs worldwide document cancers occurring during the screening interval, which are often of aggressive pathological type. Hence breast symptoms and clinical findings between screenings should be carefully evaluated.

- *Sensitivity*

Up to 10% of cancers are not visible mammographically. If there is clinical suspicion after mammographic evaluation, further evaluation with ultrasound or MRI and follow up by biopsy may still be necessary.

Patient Preparation

Provide previous breast imaging records, if applicable.

Imaging-Guided Interventional Procedures

Advances in catheter, guide-wire, stent and embolic material design have enabled interventional radiologists and other appropriately trained specialists to treat many vascular and non-vascular lesions in a minimally invasive fashion. Many of these procedures can be performed on an outpatient basis, requiring no general anesthetic or hospital confinement.

Indications

Some common examples of imaging-guided interventional procedures are given below:

- *Central nervous system*

Intracranial aneurysms, fistulae and arteriovenous malformations can be managed percutaneously using coils, detachable balloons and other embolic materials. These treatments may be definitive or as an adjunct to surgery.

- *Vascular system*

Stenosis within arteries and veins can be successfully managed with angioplasty alone or together with placement of metallic stents. Acute, subacute and some chronic vascular occlusions can be successfully treated using intraarterial or intravenous thrombolysis, often accompanied by stent placement. Percutaneous insertion of grafts is used in patients with abdominal aortic aneurysms and some patients with aortic dissection or trauma.

- *Thorax*

Malignant or inflammatory lesions within the lungs or mediastinum can be accessed via fine needle aspiration (FNA) and tissues obtained for cytology, microbiology or histology. Pneumothoraces, pleural effusions and empyemas may be drained under fluoroscopic, CT or ultrasound guidance.

- *Abdomen and pelvis*

Mass lesions in the liver, pancreas, kidneys, adrenal glands, mesentery or retroperitoneum can be biopsied using CT or ultrasound guidance. Intraabdominal or intrapelvic abscesses or collections are readily amenable to percutaneous drainage, as are biliary and urinary tract obstruction. Various techniques are used to treat inoperable hepatic lesions, e.g. laser ablation under imaging control.

- *Musculoskeletal system*

Intraarticular, bursal, tendon sheath and nerve root injections; soft tissue and lytic bony lesions biopsies are performed using fluoroscopy, ultrasound or CT guidance.

- *Others*

Lymph node biopsy is performed using ultrasound or CT guidance.

Intravascular Contrast Media

Iodinated Contrast Media

Iodinated contrast media are diagnostic drugs used for intravenous urography (IVU), angiography, venography and contrast-enhanced CT. In both IVU and CT the choice and sequence of imaging is designed to either follow the agent through the phases of distribution and excretion or to focus on one specific phase of distribution. Contrast media are particularly useful in CT for demonstrating the normal and pathological distribution of the contrast in the vascular and extravascular compartments and in detecting areas of breakdown of the blood-brain barrier.

Although classified as a drug, contrast media are remarkably well tolerated in large doses and meaningful toxicity is notably rare. Advances made in contrast media formulation have been directed towards a progressive reduction in the frequency and severity of toxicity. The current class of media is lower in osmolality and non-ionic. Non-ionic media are considered to be up to 10 times safer and have largely replaced the use of ionic contrast media. This has further reduced the incidence and severity of adverse reactions.

Risk Factors

It is not possible to predict whether a given patient will react unfavorably to intravascular contrast medium administration, but certain risk factors have been identified from large population studies. These include previous reaction to contrast media, asthma, allergy, renal or cardiac impairment and diabetes mellitus. Beta-blockers have been shown to increase the risk of anaphylactoid reactions and bronchospasm. This subgroup may be resistant to adrenaline used in resuscitation and intramuscular glucagon should be used if adrenaline is ineffective. The highest rate for severe life-threatening reactions is observed in middle-aged adults, at less than 1 per 100,000 administrations. Although the data is limited for younger individuals, children appear to be at lesser risk.

Patients at risk should preferably be given non-ionic media, whenever iodinated contrast is clearly indicated. Even for patients at high risk of reaction, the use of pre-medication is debated. Corticosteroids with or without antihistamines have been recommended but may be less effective if commenced less than 6 hours before the procedure.

Contrast Media Reactions

The vast majority of patients tolerate iodinated contrast media well. However, patients should be made aware of the potential risks of contrast media prior to its administration. The feeling of warmth or a metallic taste is relatively common following the administration of intravenous contrast media and does not indicate that an allergic reaction has occurred. A small proportion of patients experience reactions that range in severity from *mild nausea to severe circulatory failure. Severe reactions including shock from anaphylactic reactions occur in approximately 1 in 25,000 with ionic agents and even less commonly with non-ionic formulations. The risk of a fatal reaction is estimated at 1 in 170,000. These reactions are not dose-dependent (Dewachter et al 2011) and have been linked to antibody reactions with the iodinated ring-like structure common to all iodinated contrast agents. The clinical features of anaphylactic reactions usually manifest within 60 minutes, with the majority developing in the first 5 minutes. Delayed reactions occur up to one week post-injection and generally involve skin rashes without bronchospasm or laryngeal oedema. The symptoms vary widely among patients and can be roughly classified as:*

- *Cutaneous*
    - *Generalized pruritus*
    - *Flushing*
    - *Urticaria, hives or angioedema*
- *Respiratory*
    - *Laryngeal oedema with hoarseness or stridor*
    - *Bronchospasm*
    - *Respiratory failure*
- *Cardiovascular*
    - *Arrhythmias*
    - *Conduction disturbances*
    - *Vasodilatation and increased vascular permeability*
    - *Hypotension*
    - *Anaphylactic shock*
- *Neurological*
    - *Syncope*
    - *Dizziness*
    - *Seizures*
- *Gastrointestinal*
    - *Nausea and vomiting*
    - *Diarrhoea*
    - *Abdominal cramps*

Contrast-induced Nephropathy

The use of intra-arterial contrast media for angiography carries an overall risk of contrast-induced nephropathy of approximately 1.2-2.7%. Contrast-induced nephropathy (CIN) is defined as impairment of renal function indicated by a rise in baseline serum creatinine by more than 25% occurring within 3 days of contrast media administration in the absence of another aetiology. Most patients recover spontaneously within 14 days although a minority can progress to chronic renal failure and dialysis. The factors that increase the risk of contrast-induced nephropathy include:

- Pre-existing renal insufficiency;
- Insulin-dependent diabetes;
- Large volume of contrast media used;
- Concomitant use of nephrotoxic drugs, e.g. non-steroidal anti-inflammatory agents, diuretics, ACE inhibitors, aminoglycosides, amphotericin, antineoplastics, cyclosporin, lithium, methotrexate, and vancomycin;
- Cardiac failure; and
- Hyperuricemia.

Evidence suggests that a small and transient rise in creatinine is relatively common following administration of intravenous contrast media. Patients with normal or borderline-normal renal function generally do not require precautionary measures. In patients with a creatinine of >250-300mmol/L or GFR <30, iodinated contrast is contraindicated. For patients with a creatinine >150mmol/L or GFR 60-30, strategies to reduce the risk of contrast nephropathy include the use of:

- Alternative imaging, e.g. non-contrast CT, ultrasound, or MRI;
- Low osmolality or iso-osmolar contrast media - although reducing the osmolality of injected contrast media can reduce the osmotic load on the kidneys, such agents do frequently cause CIN if adequate preventative measures (e.g. hydration) are not taken;
- Intravenous hydration if not contraindicated is by far the best means to prevent CIN based on current evidence;
- Nephrotoxic drugs be ceased for at least 24 hours before and after where possible; and
- Other preventive strategies are controversial and include the premedication with N-Acetyl Cysteine, sodium bicarbonate and theophylline. Recent studies suggest that none of these measures is proven to be more superior to adequate hydration with normal saline alone for the prevention of CIN (Kilma et al 2012, Zaraca et al). Their use, although widespread as a result of a number of small randomized trials, do not appear to be strongly supported by current evidence.

Patients on metformin for diabetes are at risk of metabolic lactic acidosis with intravascular contrast. This is very rare, but the risk is increased when there is co-existent renal impairment. When contrast media administration is necessary, metformin should be discontinued, for 48 hours prior to the procedure. If there is renal impairment the patient should be kept well hydrated and the metformin restarted 48 hours following the procedure only if renal function and serum creatinine are unchanged. Patients with known renal impairment will need monitoring of renal function prior to and after the procedure. In certain severe cases, it may preclude them from receiving intravenous contrast media.

Contrast-induced Thyrotoxicosis

Thyrotoxicosis secondary to iodinated contrast media is rare but may occur in patients with abnormal thyroid function. Patients with hyperthyroidism should not be given iodinated contrast media. Patients with Graves' disease, multi-nodular goiter or other forms of thyroid autonomy, especially if they are elderly and / or live in areas of dietary iodine deficiency are at risk of iodinated contrast-induced thyrotoxicosis. An endocrinologist should monitor these patients after the administration of iodinated contrast media. In selected high-risk patients, prophylaxis prescribed by an endocrinologist may be warranted.

Contrast Media Administration During Pregnancy and Lactation

In exceptional circumstances and when deemed necessary, iodinated contrast media may be given to the pregnant mother. The theoretical risk of contrast-induced hypothyroidism within the fetus has not been validated and would seem unlikely from exposure to an organically bound iodine-containing drug. Fetal exposure to any associated free iodide is not documented with these diagnostic drugs. Were unbound iodine atoms or ions to exist, the amount is likely to be small and relatively short-lived. No adverse fetal effects due to contrast administration during pregnancy have been proven.

European guidelines have stated that cessation of breast-feeding following iodinated contrast material is not required. The amount of contrast media excreted in breast milk is very small and even if ingested by the fetus, these contrast media are not absorbed by the gastrointestinal tract. The possibility of either direct toxicity or allergic reaction is extremely remote.

Referral for Contrast Procedures

In view of the above potential side effects, requests for procedures that require intravenous iodinated contrast media should include details of the relevant risk factors. When in doubt, discussion with the imaging specialist is advisable.

MRI Contrast Media

The most commonly used MR contrast media are chelates of the rare earth element gadolinium. Gadopentetate dimeglumine is the most frequently used compound in clinical practice. The gadolinium ion produces shortening of the normal T1 relaxation time of tissue water. This produces visible 'contrast enhancement' of tissues, making them brighter or more intense on T1 weighted images. Unlike CT angiography, routine MR angiography usually requires no intravenous contrast injection. However, some types of MR angiography, such as abdominal and limb angiography, use intravenous contrast media to augment the inherent image contrast between flowing blood and adjacent tissues.

Gadolinium based contrast media are associated with a much lower incidence of adverse reactions than iodinated contrast. Most of these reactions are minor and consist of nausea, vomiting, headache, injection site *reactions, and hives. These media have no significant adverse effect on renal function in patients with renal impairment, but should not be used in patients with renal failure.*

Contrast-induced Nephrogenic Systemic Fibrosis (NSF)

Gadolinium containing contrast media have recently been associated with the development of nephrogenic systemic fibrosis (NSF) and should be avoided in patients with renal failure. NSF is a rare scleroderma-like disease characterized by thickening, induration and hardening of the skin with predilection for the distal extremities and occurs only in patients with renal failure. Over 200 cases have been recorded since it was originally described in 1997. Proximal involvement of the trunk and abdomen, including internal organs may occur. Sparing of the head and face is a distinguishing feature of NSF, along with the absence of typical serological markers associated with scleroderma. The diagnosis is confirmed by deep skin biopsy.

Biological Effects

Procedures Not Using Ionizing Radiation

Ultrasound

Ultrasound is non-invasive and does not use ionizing radiation. Therefore, when indicated, ultrasound is the most appropriate imaging modality for children and pregnant women, and in many conditions for adult patients, e.g. gallbladder, kidneys, female pelvis, testis and musculoskeletal system.

The current knowledge regarding the clinical safety of diagnostic ultrasound has been summarized by the American Institute of Ultrasound in Medicine, which states that '. . no confirmed biological effects on patients or instrument operators caused by exposures and intensities typical of present diagnostic ultrasound instruments have ever been reported. Although the possibility exists that such biological effects may be identified in the future, current data indicates that the benefits to patients of prudent use of diagnostic ultrasound outweigh the risk, if any, that may be present . . '

A prudent approach, therefore, is to use ultrasound only for medical indications and to minimize scan time during procedures.

Magnetic Resonance Imaging (MRI)

Health risks to patients undergoing MRI have not been shown at the level of magnetic field strength and radiofrequency used in the current generation of MRI scanners. Its use however is restricted during the first trimester of pregnancy unless the clinical necessity outweighs the theoretical risk. Complications can occur from the effects of the magnetic field on cardiac pacemakers, metallic implants and metallic clips. There is a particular risk that the magnetic field may cause cerebral aneurysm clips to twist or metallic foreign bodies in the eye to move. Thermal skin injuries due to excessive heating are observed in patients undergoing MR procedures associated with damaged radiofrequency coils, physiologic monitors, transdermal patches, electronically-activated devices, and external accessories or objects made from conductive materials. Clinical awareness of these effects should ensure that patients at risk are not subjected to MRI procedures.

Procedures Using Ionizing Radiation

These include: diagnostic and interventional radiology and nuclear medicine procedures.

Radiation Risks

Ionizing radiation exposure may arise outside the body for a diagnostic radiology or an imaging-guided interventional procedure (external exposure) or it may originate within the body after the administration of a radioactive isotope for a nuclear medicine scan (internal exposure).

The risk of exposure to high radiation doses is well known. However, there is less certainty regarding the risk of exposure to lower radiation doses, such as those associated with diagnostic imaging and interventional radiology. Risks of diagnostic imaging at patient doses below 50 mSv for single procedures or 100 mSv for multiple procedures over short time periods are too low to be detectable. If any risk exists at such low dose levels, it would be much lower than the normal fluctuation of the baseline / spontaneous risks. Predictions of hypothetical cancer incidence and deaths in patient populations exposed to such low doses are highly speculative and should be discouraged.

The harmful effects of ionizing radiation result from the interaction of a quantum of radiation energy with the DNA in the cell nucleus. Depending on the dose, this may cause cell death. If the affected cell mass is extensive, tissue functions may alter, thus resulting in clinically observable effects. These effects, e.g. skin burns, bone marrow dysfunction, are termed tissue reactions or 'deterministic effects'. The severity of the deterministic effects increases with dose above a dose threshold (Balter et al 2010).

Despite the robust DNA repair mechanisms, radiation exposure can induce non-lethal transformation of the irradiated cells and result in cancer induction after a long latency period. i.e. several years to decades. Effects of this type are termed probabilistic or 'stochastic'. The probability of occurrence of the stochastic effects in an individual is a function of the dose: the smaller the dose, the smaller the probability of occurrence. For the purpose of radiation protection, it is assumed as a working principle that there is a linear relationship between radiation exposure and cancer risk, with no threshold value below which this risk is zero.

The radiation dose delivered during diagnostic imaging procedures should not cause deterministic effects. However, imaging-guided interventional procedures may deliver doses that are high enough to reach the threshold for deterministic effects such as skin injuries.

The available scientific data on the biological effects of ionizing radiation are based on experimental and epidemiological studies. The most informative source of epidemiological data about human exposure to *ionizing radiation is the Life Span Study on the Hiroshima and Nagasaki atomic bomb survivors. In addition, several other sources have provided information including past accidents (e.g. Chernobyl), medical exposures (e.g. radiotherapy patients), natural radiation exposures and occupationally exposed cohorts. In general epidemiological studies showed a significant increase of cancer risk at doses above 100 mSv. However, increased cancer risks have been recently reported after lower doses, e.g. around 50 mSv, in individuals undergoing CT scans during childhood (Mathews et al 2013, Miglioretti et al 2013, Pearce et al 2102).*

Even if individual cancer risks associated with radiation exposure due to diagnostic imaging are relative small compared to the spontaneous lifetime risk of cancer in the general population, the increasingly large population being exposed to these small risks is of public health concern. In particular the stochastic risks are of concern in pediatric imaging since children are especially vulnerable and have longer life span to develop long-term radiation-induced health effects like cancer. Longer life expectancy is relevant because of the long latency period between radiation exposure and most types of clinically evident cancer. Radiation risks are strongly dependent on the age at exposure and increase at younger ages (Wakeford et al 2010).

The United Nations Scientific Committee on the Effects of Atomic Radiation has recently published a comprehensive report on the effects of radiation exposure of children. Although this report cautions the generalizations on the risks of radiation exposure during childhood, it indicates that children are clearly more radiosensitive than adults for certain types of tumors such as leukemia, thyroid, skin, breast and brain cancer (UNSCEAR 2013). As people age, their risk of radiation-induced cancer decreases. As a result, when compared to a 40 year-old, an 80 year-old is 3 to 4 times less likely to develop cancer from radiation exposure. Therefore, particular care should be employed when undertaking procedures utilizing ionizing radiation in pregnant women or children and alternative imaging such as ultrasound or MRI, should be considered if and when appropriate. Multiple imaging procedures using radiation, particularly CT scans, may reach levels of dose at which epidemiological studies showed an increase in cancer risk.

Radiation Risks Following Prenatal Exposure

The biological effects of prenatal exposure to radiation are dependent on the fetal absorbed dose and the stage of fetal development at the time of exposure. Exposure to radiation in the first week after conception may result in failure of implantation. Within the first 8 weeks after implantation, experimental models indicate that radiation exposure can be associated with malformations in the developing organs, but no human epidemiological data have confirmed these findings. Neurological effects - central nervous system abnormalities are associated with exposure to ionizing radiation doses in excess of 100 mGy between 8 to 25 weeks, with the period between 8 to 15 weeks carrying the highest risk. Epidemiological data in atomic bomb survivors who were exposed prenatally indicated that the severity of abnormalities range from a slight reduction in IQ with doses of 100-200 mGy to severe mental retardation and microcephaly at doses of 1,000 mGy.

Fetal exposure to radiation can increase the risk of developing childhood cancer and leukemia. It was estimated that doses of about 10 mGy received by the fetus in utero produce a consequent increase in the risk of childhood cancer. The estimated excess absolute risk for childhood cancer due to prenatal exposure is approximately 6% per gray for all solid cancers and 2% per gray for leukemia (Doll and Wakeford 1997). Few studies have addressed the potential risk of adult cancer after prenatal exposure. The atomic bomb survivors who were exposed in utero are now in the period of life when the baseline incidence of adult cancer increases markedly, so more data are expected in the future.

There is no human epidemiological data on the hereditary effects of radiation exposure. For radiation protection purposes, it is considered that this risk is extremely low, compared to both radiation-induced carcinogenesis and the natural risk of heritable effects. Gonadal irradiation of the parents prior to conception has not been shown to cause an increased risk of carcinogenesis or malformations in children.

Radiation Protection

Ionizing Radiation Sources

Ionizing radiation is energy, released by atoms, that travels as electromagnetic waves (gamma or x-rays) or particles (neutrons, beta or alpha). The spontaneous disintegration of atoms is called radioactivity, and the excess energy emitted is a form of ionizing radiation. Unstable elements that disintegrate and emit ionizing radiation are called radionuclides.

People are constantly exposed to natural radiation. Natural radiation comes from many different sources including more than 60 naturally occurring radioactive materials found in soil, water and air. Radon, a naturally occurring radioactive gas found in rock and soil, is the main source of natural radiation. Every day, people inhale and ingest radionuclides from air, food and water.

People are also exposed to natural radiation from cosmic rays, particularly at high altitude. On average, 80% of the annual dose that a person receives from background radiation is due to these naturally occurring terrestrial and cosmic radiation sources. For example, the average annual global natural background radiation is approximately 2.4 mSv. Background radiation levels vary due to geological differences and the exposure in certain areas can be more than many times higher than the global average. Human exposure to radiation also comes from man-made sources ranging from nuclear power generation to the medical uses of radiation for diagnosis or treatment. Today, the most common man-made sources of ionizing radiation are from x-ray equipment and other medical devices.

Radiation exposure may be internal or external, and can be incurred by various exposure pathways. Internal exposure to ionizing radiation occurs when a radionuclide is inhaled, ingested, injected or otherwise enters into the bloodstream, e.g. via wounds. In diagnostic imaging, internal exposure is incurred as a result of nuclear medicine procedures. Internal exposure stops when the radionuclide is eliminated from the body, either spontaneously e.g. through excreta or as a result of treatment. External contamination may occur when radioactive material (dust, liquid, aerosols) is deposited on the skin or clothes. This type of radioactive material can often be removed from the body by simple washing. Diagnostic imaging procedures using ionizing radiation, e.g. with x-rays in radiography, fluoroscopy and CT, is a form of external exposure. External irradiation stops when the radiation source is turned off or when the person moves outside the radiation field.

Measurement of Radiation Dose

Absorbed Dose

Measured in Grays or milliGray (Gy or mGy), the absorbed dose represents the energy deposited in tissue per unit mass. This unit of measurement can be used for any form of radiation and does not account for the different biological effects of different types of radiation.

Equivalent Dose

Measured in Sieverts (Sv), the equivalent dose equals the absorbed dose multiplied by the appropriate radiation-weighting factor (WR) taking into account the biological effects of the different types of radiation. WR is 1 for photons (x-rays and gamma rays) and is 2 for protons.

Effective Dose

Also measured in Sieverts (Sv), the effective dose is a summation of the equivalent doses to all organs and tissues, after an adjustment for their varying radiosensitivity. It is a tissue-weighted dose that takes into account the sensitivity of different tissues and organs to ionizing radiation. Table 2 shows the new tissue weighting factors (WT) recommended in the ICRP Report 103 for different tissues and organs. The Sv is a rather large unit, so it is more practical to use smaller units such as millisieverts (mSv) or microsieverts (μSv). In addition to quantifying the amount of radiation exposure (dose) in mSv or μSv, it is also useful to express the radiation exposure rate (dose rate) by using μSv/hour or mSv/year.

Tissue / Organ	Tissue weighing factor
Gonads	0.08
Red Bone Marrow	0.12
Colon	0.12
Lung	0.12
Stomach	0.12
Breast	0.12
Bladder	0.04
Liver	0.04
Oesophagus	0.04
Thyroid	0.04
Skin	0.01
Brain	0.01
Salivary glands	0.01
Bone Surface	0.01
Remainder	0.12

Table 2: Tissue weighting factors (WT) for specific organs (ICRP 2007a)

The effective dose provides a single dose estimate related to the total radiation risk, no matter how the radiation dose is distributed around the body. It is important to note that since effective dose does not usually delineate differences in risk based on age and sex, it cannot accurately specify risk for an individual patient. However, effective dose does provide a way to approximately compare relative risks between different imaging procedures, if the representative patients or patient populations for which the effective doses are derived are similar with regard to age and sex.

Typical Effective Doses for Common Diagnostic Imaging Procedures

As a general guide, the typical effective doses for the common diagnostic imaging procedures are listed in Table 3. It should be noted that these figures are subjected to a great deal of variability depending on equipment, technique, number of exposures and series required. For example, the effective dose for fluoroscopy and angiography varies considerably and could be very high due to unnecessarily or inappropriately long fluoroscopic time or ineffective collimation, leading to skin burns, hair loss etc (Miller et al 2012).

Procedures	Effective dose (mSv)	Equivalent number of # CXR	Equivalent period of natural radiation
Radiography			
Extremities	0.01	0.5	1.5 days
Chest	0.02	1	3 days
Skull	0.07	3.5	11 days
Cervical Spine	0.10	5	15 days
Thoracic Spine	0.70	35	4 months
Lumbar Spine	1.30	65	7 months
Hip	0.30	15	7 weeks
Pelvis	0.70	35	4 months
Abdomen	1.00	50	6 months
IVP	2.50	125	14 months
Barium Swallow	1.50	75	8 months
Barium Follow through	3.00	150	16 months
CT			
Head	2.30	115	1 year
Cervical Spine	1.50	75	8 months
Thoracic Spine	6.00	300	2.5 years
Chest	8.00	400	3.6 years
Lumbar Spine	3.30	165	1.4 years
Abdomen	10.0	500	4.5 years
Pelvis	10.0	500	4.5 years
Nuclear medicine			
Bone Imaging (Tc99m)	4.00	200	1.6 years
Cerebral Perfusion (Tc99m)	5.00	250	2 years
Lung Ventilation (Xe133)	0.30	15	7 weeks
Lung Perfusion (Tc99m)	1.00	50	6 months
Myocardial Perfusion (Tc99m)	6.00	300	2.5 years
Whole Body PET (FDG)	10.0	500	4 years
Thyroid Imaging (Tc99m)	1.00	50	6 months
DTPA Renogram	2.00	100	10 months
DMSA Renogram	0.70	35	3.5 months
HIDA Hepatobilliary Imaging	2.30	115	1 year

Table 3: Typical effective doses for common procedures (EC 2000, UNSCEAR 2010).

Relative Radiation Levels

The relative radiation level (RRL) is based on effective dose. In this publication, the following RRL classification scheme is used as shown in Table 4 (ACR 2013b, Huda et al 2002).

RRL	Adult effective dose (mSv)	Pediatric effective dose (mSv)	Examples
None	0	0	Ultrasound, MRI
☢	< 0.1	< 0.03	CXR, XR limbs
☢☢	< 1	< 0.3	XR pelvis, mammography
☢☢☢	1-10	0.3-3	Nuclear bone scan, CT neck, CT body
☢☢☢☢	10-30	3-10	CT multiple regions, whole body PET
☢☢☢☢☢	>30	>10	Aortic aneurysm stent placement

Table 4: Relative radiation levels (RRL) for imaging procedures.

Radiation-induced cancer mortality risk in children is 3 to 5 times higher than for adults, due to increased organ sensitivity and longer life expectancy. Longer life expectancy is relevant because of the long latency period between radiation exposure and most types of clinically evident cancer. It is particularly important to consider radiation exposure levels when selecting appropriate imaging procedures for children due to their significantly greater sensitivity to radiation exposure, even though radiation levels required for imaging procedures of children are generally lower than those for adults. Unless pediatric-specific, indication-based and weight-based protocols are used for CT, effective doses for small patients and children may exceed typical adult effective doses. It is important to note that as people age, their risk of radiation-induced cancer decreases. As a result, when compared to a 40 year-old, an 80 year-old is 3 to 4 times less likely to develop cancer from radiation exposure.

Individual Dose Record

Many new CT and digital radiography systems provide patient dose information for the procedure performed. When this data could be easily extracted, it should be included in the report for the procedure and be an integral part of the patient's health record (Frush et al 2014). Advances in CT technology have increased its use to a point at which patient radiation dose arising from repeated procedures on the same individual in many instances may exceed 100 mSv. It has been recently suggested that the availability of previous imaging records and radiation dose / exposure-tracking data may minimize unjustified CT procedure and facilitate optimized and more patient-specific studies (Seuri et al 2013). This cumulative dose could become significantly high in patients with chronic illness requiring repetitive procedures. It is particularly important in children because of their sensitivity to the effects of ionizing radiation and longer life span, as described above.

Radiation Protection Measures

The system of radiological protection aims to control radiation risks without unduly limiting the potential benefits for individuals and society. Achieving this balance is becoming increasingly challenging in medicine. Justification and optimization are the two pillars of radiological protection in health care. The International Commission on Radiological Protection recommends that procedures using ionizing radiation should be carried out only if it is likely that the information obtained will be useful for the management of the patient or for improving the health status of the population (ICRP 2007b). If this recommendation is to be followed, any potential risk of performing such procedures should be less than the risk of missing a treatable disease.

The key measures used to improve quality, radiation safety and appropriate use of radiation in medicine are:

- *Procedure justification;*
- *Optimization of image quality, diagnostic information and radiation protection; and*
- *Error avoidance.*

Procedure Justification

The principle of justification of diagnostic imaging procedures is applied at three levels. First, the use of ionizing radiation in medicine is acceptable if it will do more good than harm to society – radiation exposure, economic and social issues being considered. This level of justification is usually taken for granted. Second, the objective for a given procedure is clearly defined and justified, e.g. a chest x-ray is indicated for a patient with a defined set of symptoms and signs or for a group of individuals who are at risk to a condition that can be detected and treated. The aim of this second level of justification is to consider whether the procedure will improve diagnosis or treatment, or will provide the information to assist patient management. Third, the application of the procedure to an individual patient should be justified, i.e. the procedure should be able to do more good than harm to a particular individual. Therefore, a radiology procedure is justified by taking into account the specific objectives and the needs of an individual, i.e. individual justification. Evidence-based referral guidelines are useful tools for individual justification.

Optimization of Image Quality, Diagnostic Information and Radiation Protection

The optimization of protection is applied to the design, selection, construction and installation of appropriate equipment, and to the daily working procedures. The basic aim is to have protective measures in place to ensure that the images obtained are of good quality and the diagnostic information provided are adequate for the clinical purpose with the lowest dose possible, i.e. the dose commensurate with the medical purpose, thus maximizing the net benefit. The use and selection of measures will depend on the available resources and will have an impact on the exposure and risk to the patient, the staff, and sometimes the public as well as financial implications.

Dose limits do not apply to medical exposures in general and therefore they are not applicable to patients receiving diagnostic imaging procedures. However, "Diagnostic Reference Levels" (DRLs) are used in imaging facilities as optimization and quality improvement tools to indicate whether, in routine conditions, the patient dose for a specified procedure is unusually high, low or optimal.

Diagnostic and Interventional Radiology

The minimum number of exposures needed to give a satisfactory procedure should be obtained using well-maintained equipment, appropriate exposure settings, adequate collimation and, when appropriate, gonadal shielding. For fluoroscopy, angiography and fluoroscopy-guided interventions, collimation must be used effectively, fluoroscopy time minimized and the lowest fluoroscopic dose rate and pulse rate that provide adequate image quality employed to reduce exposure and radiation detriment to patients and staff. Fluoroscopy should be used only to observe moving structures.

Computed Tomography

The protocol should use the minimal number of series and exposure factors necessary to obtain the required information. High mA settings and thin slices will result in increased radiation exposures. This dose will be compounded if multiple series are performed. In children, indication-based and weight-based protocols should be employed. When choosing the settings, the imaging team must always balance the radiation exposure against the need to obtain adequate diagnostic information. New CT scanners offer hard and software innovations to optimize exposure and improve image quality, e.g. the use of iterative reconstruction. DRLs are used by imaging facilities to improve awareness, evaluate performance, and identify improvement opportunities to optimize and reduce exposure.

Nuclear Medicine

Radiation exposure of patients undergoing nuclear medicine procedures is due to internal irradiation resulting from the radiotracer present in the body. The ionizing radiation has the same effect as for diagnostic radiology or CT. In nuclear medicine, DRLs are expressed in terms of the administered activity. The radiation dose depends on the isotope used and the amount given and is tailored for each procedure with appropriate dose adjustment for children. The ultimate goal is to reduce radiation exposure to the lowest possible levels commensurate with the indication for the procedure and the required diagnostic imaging data.

Error Avoidance

Exposure errors could be due to faulty equipment installation or calibration, incorrect use of protocol or settings, limited time allocated for a procedure, knowledge and experience gaps, inadequate training or communication breakdown. An understanding of the reasons for these errors will guide the development and implementation of control tools. Clinical audit, quality control, quality assurance and quality improvement actions, will minimize errors, risks and the subsequent adverse events. Primary prevention being essential, *adverse event reporting and learning systems can enhance patient safety by contributing to learning from failures of the health care system (Mandel and Runciman 2014). These systems should lead to a constructive response based on analysis of the risk profiles, dissemination of the lessons, and implementing the control measures for these adverse events.*

Diagnostic Imaging During Pregnancy

In addition to the general radiation protection measures mentioned above, the following steps should be used to avoid inadvertent exposure or minimize exposure to ionizing radiation in a patient of childbearing age:

- *Promote an awareness of the need for the patient and referrer to inform the imaging specialist and technologist of the possibility of pregnancy;*
- *Prior to a procedure using ionizing radiation, women of childbearing age should be asked if they are, or could be, pregnant;*
- *If a patient cannot exclude the possibility of pregnancy, non-urgent procedures involving ionizing radiation should be delayed until pregnancy is excluded or restricted to the first ten days from the beginning of menses, the clinical condition permitting ('10 day rule'); and*
- *When clinically appropriate, use procedures that do not require ionizing radiation.*

Each procedure should be assessed individually, involving a risk-benefit analysis weighing up the potential maternal and fetal benefits against potential harm to the fetus. Procedures involving ionizing radiation should be avoided or delayed until after the pregnancy unless there are strong clinical indications. The urgency of the investigation should be assessed against the gestational age, with special care taken to avoid the use of ionizing radiation during the first trimester. The responsibility for performing the procedure should be shared after consultation with the referring clinician.

The imaging modality with the lowest level of ionizing radiation should be chosen. Consideration should be given to modalities such as ultrasound and MRI, which do not involve exposure to ionizing radiation. If CT is deemed necessary, the absorbed dose could be minimized by:

- *Shielding of organs or the fetus;*
- *Reducing number of series;*
- *Reducing mAs;*
- *Limiting the volume scanned;*
- *Eliminating unnecessary scout views;*
- *Choosing appropriate image reconstruction parameters;*
- *Using thicker detector collimation; and*
- *Increasing pitch factor.*

It is the responsibility of the imaging specialist performing the procedure and the referrer to take all reasonable steps to inform the patient about the estimated fetal absorbed dose and the potential risks to the fetus. In each case, the joint decision and the basis for justification whether to proceed or not should be clearly documented. Whilst this information should be provided to the patient prior to undertaking the procedure, this may not be possible in certain emergency situations. For procedures where the fetal absorbed dose is less than 1 mGy, it is sufficient to advise the pregnant patient that the risks are negligible. Imaging procedures associated with doses greater than 1 mGy require a more thorough discussion (Dauer et al 2012).

Inadvertent Radiation of Pregnant Patients

As previously described, the biological effects of radiation on the fetus are dependent on the fetal absorbed dose and the stage of fetal development at the time of exposure. The estimated fetal doses for common procedures are listed in Table 5 (Dauer et al 2012, Sharp et al 1998).

Procedure	Mean fetal dose (mGy)	Maximum fetal dose (mGy)
Radiography		
Chest	<0.01	<0.01
Skull	<0.01	<0.01
Thoracic Spine	<0.01	<0.01
Lumbar Spine	1.70	10.0
Pelvis	1.10	4.00
Abdomen	1.40	4.20
IVP	1.70	10.00
Barium Enema	6.80	24.0
CT		
Brain	<0.005	<0.005
Chest	0.06	0.96
Abdomen	8.00	49.0
Pelvis	25.0	79.0
Pelvimetry	0.02	0.04

Table 5: Estimated fetal doses for common procedures.

Except for some interventional procedures in the lower abdomen or pelvis, for properly performed procedures the fetal absorbed dose is unlikely to exceed 100 mGy even when the uterus is in the direct beam. Therefore for a clinically indicated procedure, the potential benefits will usually outweigh any potential risks from irradiation.

If a fetus is inadvertently exposed to high-dose irradiation, the fetal absorbed dose must be calculated and the risk to the fetus estimated by a qualified medical physicist, after accounting for all the doses received from *imaging procedures during this pregnancy. However accurate risk estimation and dose calculation could be challenging in some settings due to equipment software, maintenance and quality assurance. This risk to the fetus from the exposures is usually low and unlikely to justify the greater risks of invasive fetal diagnostic procedures (e.g. amniocentesis) or those of a termination of the pregnancy. This radiation risk assessment should be communicated to and fully discussed with the patient by the imaging specialist together with the referrer or the patient's obstetrician.*

Good Medicine and Sharing Responsibilities

Joint Responsibilities

The referrer and imaging specialist shall:

1. *Recognize and respect the primacy of the patient. Patient care is individual-oriented, including: respect for dignity and confidentiality, participation in decision-making, promptness, quality of amenities and choice of provider.*
2. *Avoid unnecessary duplication of procedures, by:*
    a. *Reviewing any recent or relevant procedures performed prior to requesting, including those procedures requested by others;*
    b. *Ensuring that the patient is aware of the importance of proper maintenance of previous records and brings these along for review during the next procedure; and*
    c. *Noting the need and appropriate interval for a follow up procedure, which varies with the disease process and the procedure.*
3. *Ensure that the most appropriate procedure is selected and performed. The care, intervention or action provided is relevant to the patient's need and based on established standards. The imaging specialist is the clinical consultant assisting the referrer and the patient in selecting the most appropriate procedure for the clinical condition, by using evidence-based referral guidelines.*
4. *Select procedures that are effective and that achieve the desired outcome.*
5. *Whenever possible and appropriate, and especially in children, select procedures that do not employ ionizing radiation.*
6. *Be aware that many procedures carry both radiation risk and other risks, and based on this knowledge determine whether the potential benefits of the procedure outweigh the potential risks. Avoid or minimize actual or potential harms from the procedures, including radiation exposure and contrast media.*
7. *Avoid the use of ionizing radiation in a pregnant patient by:*
    a. *Promoting an awareness of the need for the patient and referrer to inform the imaging specialist and technologist of the possibility of pregnancy;*
    b. *Confirming and documenting the pregnancy status and adhering to the "10 day rule". If a patient cannot exclude the possibility of pregnancy, non-urgent procedures involving ionizing radiation should be delayed until pregnancy is excluded or restricted to the first ten days from the beginning of menses, the clinical condition permitting;*
    c. *Selecting procedures that do not employ ionizing radiation, when clinically appropriate; and*
    d. *Discussing and sharing the decision and responsibility should there be an over-riding urgent clinical situation that requires the use of ionizing radiation in a pregnant or possibly pregnant patient.*

Referrer Responsibilities

The referrer shall:

1. *Request a procedure only if the results will potentially alter patient management. However, it is acknowledged that exclusion of disease in certain circumstances may provide important reassurance for the referrer and patient.*
2. *Provide adequate and relevant clinical details to the imaging specialist. In most situations, a more useful report will be forthcoming if the imaging specialist is provided with the clinical history relevant to and the reasons for the procedure.*
3. *Ensure that imaging procedures are not a substitute for obtaining a history and examining the patient.*
4. *Consult with the imaging specialist when required, especially when there is difficulty in selecting a procedure for a complex clinical condition.*

Imaging Specialist Responsibilities

The imaging specialist shall:

1. *Be capable of providing quality diagnostic imaging procedures based on skill, competency and knowledge.*
2. *Lead the imaging team and ensure that the radiation exposure used is as low as reasonably achievable in accordance to the optimization principle by managing the radiation dose so that it is commensurate with the medical purpose.*
3. *Adhere to the principle of optimization of protection by using shielding when appropriate, appropriate technical factors, and the minimum exposures to obtain the diagnostic information required.*
4. *Avoid repeat exposures by supervising quality control, quality assurance and quality improvement measures.*
5. *Provide a timely and accurate report. Procedures should be accurately interpreted, fully documented and the report delivered to the referrer in a timely manner for optimal patient management. The need for promptness should be balanced with the need for accuracy. Reliable means of report delivery and confirmatory mechanisms are essential especially in the case of urgent, significant or unexpected findings.*

Informed Consent

In most settings, it is impractical and unlikely implementable for informed consent to be obtained for every routine procedure. However, when substantial risk is involved for a given procedure, as determined by knowledgeable experts, informed consent should be obtained, e.g. radiation procedure in pregnancy, interventional procedure etc. Informed consent is a process in which a proposed procedure or decision is discussed with the patient to enable the patient's informed, autonomous and voluntary participation in his or her own health care. A surrogate representative is applicable in situations when the patient's mental competency to make a decision is deemed to be inadequate. Regulations and procedures with respect to surrogate representatives are subject to evolution and differ between countries. It is a patient's legal and *ethical right to decide on his or her treatment options. For the purposes of diagnostic imaging or interventional radiology procedures, the elements of informed consent include:*

- *Nature of the proposed procedure;*
- *Risks, including ionizing radiation, and benefits of the proposed procedure;*
- *Alternative procedures;*
- *Risk and benefits of these alternative procedures; and*
- *Risk and benefits of not undergoing the procedure.*

It must be emphasized that the details of disclosure may vary among patients because the different risks and adverse outcomes are of different importance to different patient. Any documents prepared for the purposes of informed consent must therefore be flexible, to allow for the varying requirements of individual patients. These documents must also conform to the legal requirements of the competent authority.

Section II

Referral Guidelines for Diagnostic Imaging

These referral guidelines aim to promote the selection of appropriate diagnostic imaging procedures <u>*for selected conditions*</u> *and to ensure such procedures are justified and indicated. The optimization of imaging data and radiation protection is the next step after a procedure is selected and is outside the scope of these guidelines. The guidelines are based on common recommendations from the American College of Radiology, the Royal College of Radiologists and the Western Australian Government Department of Health at the time of preparation of this document. However, users are advised to monitor the evolving trends and the updated recommendations as they do change over time.*

The recommendations are available from the following sites:

- *American College of Radiology: "ACR Appropriateness Criteria®"*
  Open access from: http://www.acr.org/Quality-Safety/Appropriateness-Criteria
- *Department of Health Western Australia: "Diagnostic Imaging Pathways"*
  Open access from: http://www.imagingpathways.health.wa.gov.au/includes/index.html
- *Royal College of Radiologists: "iRefer: Making the Best Use of Clinical Radiology"*
  Member access or purchase from: http://www.rcr.ac.uk/publications.aspx?PageID=310&PublicationID=362

N1 Thunderclap Headache

When a patient presents with a "thunderclap headache", acute onset of the worst headache in his / her life, a subarachnoid hemorrhage (SAH) must be suspected and imaging should be obtained urgently to diagnose the cause and facilitate treatment if a SAH is present.

The best imaging is CT combined with CTA if the CT shows subarachnoid hemorrhage.

Imaging	Modality	RRL	Comments
Recommendation	*CT*	☢☢☢	
Further remarks			

N2 Stroke

In a patient presenting with stroke or suspected stroke, urgent imaging is needed to determine the type: haemorrhagic or non-haemorrhagic, determine viable brain tissue, and to exclude other lesions, so that a decision regarding thrombolytic therapy can be made.

There is no longer consensus that non-contrast CT is the best initial imaging modality. If a centre has an active interventional stroke treatment program, MRI is often used as the initial imaging modality. However, if interventional treatment is not available, non-contrast CT is still an appropriate initial imaging modality.

Imaging	Modality	RRL	Comments
Recommendation	*CT*	☢☢☢	*See comments above.*
	MRI	*Nil*	*See comments above.*
Further remarks			

N3 Transient Ischaemic Attack (TIA)

In a patient with TIA, the aim of imaging is to rule out haemorrhage or any underlying structural causes, which can mimic TIA. In view of the significant risk of stroke following a TIA, early diagnostic workup is recommended. Imaging of the neck arteries is used to assess the degree of stenosis and suitability for carotid endarterectomy or stenting.

The imaging modalities of choice are CT of the brain and Doppler ultrasound of the neck arteries.

Imaging	Modality	RRL	Comments
Recommendation	*CT*	☢☢☢	
	Doppler ultrasound	*Nil*	
Further remarks			

N4 Head Trauma

Immediate neuro-imaging is indicated for a patient with:

1. *Glasgow Coma Scale (GCS) <12; or*
2. *GCS >12 but with fixed neurological deficit, witnessed loss of consciousness, definite amnesia, or witnessed disorientation [Canadian Head CT rule (Stiell et al 2001) or the similar New Orleans criteria].*

High risk for brain injury requiring neurological intervention - CT indicated:

- *GCS score <15 at 2 hr after injury;*
- *Suspected open or depressed skull fracture;*
- *Any sign of basal skull fracture (haemotympanum, 'raccoon' eyes, cerebrospinal fluid otorrhoea / rhinorrhoea, Battle's sign);*
- *Vomiting > two episodes; or*
- *Age > 65 years.*

In a patient with severe head trauma, imaging of the cervical spine should be included to exclude upper cervical spinal fracture.

The imaging modality of choice is CT.

Imaging	Modality	RRL	Comments
Recommendation	*CT*	☢☢☢	
Further remarks			

N5 Headache

Imaging is indicated only if headache is associated with red-flag features (also referred to as new or focal features). The red flag features are:

- *Thunderclap headache (refer to guideline for thunderclap headache);*
- *New headache in an older population;*
- *New onset headache with history of cancer or immunodeficiency;*
- *New onset of headache in a patient on anti-coagulation therapy;*
- *Headache with mental state changes;*
- *Headache with fever, neck stiffness and meningeal signs;*
- *Headache with focal neurological deficit if not previously documented as a migraine with aura;*
- *Substance abuse with amphetamine or cocaine;*
- *Patient is pregnant or post-partum;*
- *Headache causing wakening from sleep or worsened by Valsalva maneuver;*
- *Progressively worsening headache; or*
- *Significant trauma.*

Either MRI or CT can be used. CT is acceptable for initial imaging evaluation, particularly if MRI is unavailable or contraindicated. MRI is the best imaging modality because it avoids radiation and provides the most detailed imaging of the brain.

Imaging	Modality	RRL	Comments
Recommendation	*CT*	☢☢☢	
	MRI	*Nil*	
Further remarks			

N6 Vertigo

In a patient presenting with vertigo, MRI brain (including internal auditory canal) is the investigation of choice. CT may be used for assessment of the bony labyrinth. Imaging is not indicated for benign postural vertigo.

Imaging	Modality	RRL	Comments
Recommendation	*MRI*	*Nil*	
	CT	☢☢☢	*Assessment of bony labyrinth.*
Further remarks			

N7 Seizure

Certain seizures are associated with structural brain lesions like tumor, infarct, brain injury, developmental abnormalities and seizure-associated brain pathology. In an adult patient with first (or new onset) seizure, imaging is indicated. Imaging is not usually of value in idiopathic generalized epilepsy.

The best imaging modality is MRI but CT is used if MRI is not available or feasible or when the patient presents with seizure as an acute neurological condition.

Imaging	Modality	RRL	Comments
Recommendation	*MRI*	*Nil*	
	CT	☢☢☢	*If MRI is not available or feasible or when the patient presents with seizure as an acute neurological condition.*
Further remarks			

N8 Dementia

The primary role of neuro-imaging in patients with dementia is to exclude other significant intracranial abnormalities.

The imaging modality of choice is either MRI or CT.

Imaging	Modality	RRL	Comments
Recommendation	*MRI*	*Nil*	
	CT	☢☢☢	
Further remarks			

N9 Orbital Trauma

In a patient with clinically significant orbital trauma, or head injury with visual loss, imaging is indicated.

The imaging modality of choice is CT. If CT is not available, x-ray can be used. A good radiograph of the orbits can be used to diagnose an orbital floor blowout fracture.

Imaging	Modality	RRL	Comments
Recommendation	*CT*	☢☢☢	
	X-ray	☢	
Further remarks			

N10 Orbital Pathology and Non-Traumatic Visual Loss

In a patient with orbital pathology or new-onset visual loss or disturbance, imaging is indicated and a compartmental approach facilitates differential diagnosis.

Imaging modalities of choice are MRI and CT, which play complementary roles – MRI is preferable for evaluation of soft tissue structures and retro orbital regions, while CT is well suited for bony structures and orbital lesions.

Imaging	Modality	RRL	Comments
Recommendation	*MRI*	*Nil*	*For the evaluation of soft tissue structures and retro orbital regions.*
	CT	☢☢☢	*For the evaluation of bony structures and orbital lesions.*
Further remarks			

E1 Acute Sinusitis

No imaging is recommended in acute uncomplicated sinonasal disease, which should be diagnosed clinically. In a patient with persistent, acute sinusitis not responding to appropriate medication or with complications (e.g. orbital involvement or neurological deficit) or a patient with recurrent sinusitis, imaging is indicated.

The imaging modality of choice is CT.

Imaging	Modality	RRL	Comments
Recommendation	*CT*	☢☢☢	
Further remarks			

E2 Chronic Sinusitis

CT is the best imaging modality to show the presence and distribution of disease and to evaluate sinonasal anatomy before functional endoscopic sinus surgery.

Imaging	Modality	RRL	Comments
Recommendation	*CT*	☢☢☢	
Further remarks			

M1 Myelopathy (Non-traumatic, Suspected Tumor, Inflammation, Infarction etc.)

Myelopathy refers to neurological deficit resulting from diseases involving the spinal cord. The primary aim of imaging in myelopathy is to determine the cause and assess cord morphology.

The imaging modality of choice is MRI (with or without IV contrast). However, CT is indicated if bony detail is required.

Imaging	Modality	RRL	Comments
Recommendation	*MRI*	*Nil*	
Other option	*CT*	☢☢☢	*If bony detail is required.*
Further remarks			

M2 Non-traumatic Neck Pain

In patients with isolated neck pain (non-traumatic, without associated neurological signs and symptoms), imaging is seldom justified. When indicated, MRI is the investigation of choice for those patients with neck pain associated with neurological signs and symptoms.

X-ray is not generally helpful and is not indicated in patients with chronic neck pain, but x-ray may be helpful for patients without neurological signs and symptoms but with other 'red-flag' conditions (e.g. fever, cancer, trauma, immuno-suppression, rheumatoid condition etc.).

Imaging	Modality	RRL	Comments
Recommendation	*MRI*	*Nil*	*Neck pain with neurological signs and symptoms.*
	X-ray	☢	*No neurological symptoms or signs but with 'red-flag' conditions.*
Further remarks			

M3 Low Back Pain

Uncomplicated acute low back pain is common, usually benign and self-limiting which does not normally require imaging. In patients presenting with low back pain, imaging is only indicated if there are associated the following symptoms and signs (red flags):

- *Recent significant trauma (even mild trauma if age > 50 years);*
- *Unexplained weight loss;*
- *Unexplained fever;*
- *Compromised immune system;*
- *History of cancer;*
- *I.V. drug user;*
- *Osteoporosis or steroid use; or*
- *Age > 70 years.*

Imaging is also indicated if the back pain persists after an appropriate course of medical therapy.

The imaging modality of choice is MRI, but CT can be used if MRI is unavailable or contraindicated. X-rays may be useful for initial imaging if a fracture is suspected, e.g. in patients with osteoporosis or possible metastatic disease.

Imaging	Modality	RRL	Comments
Recommendation	*MRI*	*Nil*	
Other options	*CT*	☢☢☢	*CT if MRI is unavailable or contraindicated.*
	X-Ray	☢	*X-rays be useful for initial imaging.*
Further remarks			

C1 Haemoptysis

While many causes of haemoptysis are self-limiting and not associated with significant pathology, haemoptysis may be the only clue to an underlying lesion such as a bronchogenic cancer, bronchiectasis or tuberculosis. In a patient with haemoptysis, imaging is usually only indicated if the haemoptysis is massive or recurrent, or if it is associated with risk factors such as a history of smoking or age >40 years.

The imaging modalities of choice are CXR and CT. CT may detect malignant and non-malignant disease not identified on CXR or bronchoscopy. However, it is insensitive in detecting mucosal and sub-mucosal disease.

Imaging	Modality	RRL	Comments
Recommendation	*CXR*	☢	
	CT	☢☢☢	
Further remarks			

C2 Acute Respiratory Illness

Acute respiratory infections are common and the majority of patients do not require imaging before commencing treatment. The factors indicating the need for imaging include: >40 years of age, haemoptysis, focal signs, leucocytosis, immunosuppression, hypoxia or a past history of dementia, tuberculosis, cardiac failure or coronary artery disease.

A patient with an exacerbation of COPD or asthma does not require a CXR with every episode. The above list, severity of attack and the likelihood of complication such as a pneumothorax should be taken into account prior to requesting a CXR. The likelihood of detecting a radiographic abnormality is higher if physical signs are present or there is a significant clinical history.

If imaging is clinically indicated the modality of choice is CXR.

Imaging	Modality	RRL	Comments
Recommendation	*CXR*	☢	
Further remarks			

C3 Pre-operative CXR

Routine pre-operative chest x-ray is not indicated except in a patient with signs or history of cardio-respiratory disease. Although there is no high quality evidence to support the practice, a CXR may be obtained before cardio-thoracic surgery.

Imaging	Modality	RRL	Comments
Recommendation	*Routine CXR is not indicated.*		
Further remarks			

C4 Suspected Aortic Dissection

In a patient presenting with acute chest pain and suspected aortic dissection, urgent imaging is indicated.

CXR is recommended in all patients presenting with acute chest pain and should be performed if it is readily available at the bedside and does not cause delay in more definitive imaging. CXR is used mainly to exclude other causes of chest pain. If aortic dissection is still suspected after the CXR, CT angiography (CTA) is the best imaging modality.

Imaging	Modality	RRL	Comments
Recommendation	*CXR*	☢	*A normal chest x-ray does not exclude an aortic dissection.*
	CTA	☢☢☢	*CTA without and with contrast is the best imaging modality to diagnose aortic dissection.*
Further remarks			

C5 Blunt Chest Trauma – Suspected Aortic Injury

In a patient with blunt chest trauma and suspected aortic injury, prompt diagnosis and treatment are essential.

The imaging modalities of choice are CXR and CT angiography (CTA). Erect CXR is useful to exclude a pneumothorax and to show pleural fluid or lung contusion. CT is the best imaging modality to evaluate aortic injury and to exclude suspected pneumothorax not shown in a supine CXR.

Imaging	Modality	RRL	Comments
Recommendation	*CXR*	☢	*An immediate supine examination should be obtained, but an erect examination is also helpful if feasible.*
	CTA	☢☢☢	
Further remarks			

V1 Abdominal Aortic Aneurysm

In a patient with suspected abdominal aortic aneurysm (AAA), imaging is indicated for confirmation, follow up and pre-interventional assessment.

The imaging modality of choice for initial examination and follow up for an asymptomatic AAA is ultrasound. CT angiography (CTA) is the best modality if the patient is symptomatic and is indicated for detailed anatomical assessment prior to endovascular or surgical intervention.

Imaging	Modality	RRL	Comments
Recommendation	*Ultrasound*	*Nil*	
	CTA	☢☢☢	*For assessment prior to intervention.*
Further remarks			

V2 Suspected Deep Venous Thrombosis

In a patient with suspected lower extremity deep venous thrombosis (DVT), the primary aim of imaging is to confirm the presence of thrombosis and to determine its location and extent.

The imaging modality of choice is ultrasound with Colour Doppler. Apart from confirming DVT, ultrasound can diagnose other conditions, which could clinically mimic DVT, e.g. ruptured Baker's cyst or muscle tear.

Imaging	Modality	RRL	Comments
Recommendation	*Colour Doppler Ultrasound*	*Nil*	*For a diagnosis of DVT and DVT mimics, e.g. ruptured Baker's cyst or muscle tear.*
Further remarks			

V3 Suspected Acute Lower Limb Ischemia

CT angiography (CTA) and MR angiography (MRA) are now considered to be the best initial imaging modalities, and imaging evaluation should include the arteries from the renal arteries to the feet. Digital Subtraction Angiography (DSA) is now only used as part of an interventional procedure.

Imaging	Modality	RRL	Comments
Recommendation	*CTA*	☢☢☢	*Imaging should be obtained urgently.*
	MRA	*Nil*	
	DSA	☢☢☢	*DSA is only used as part of an interventional procedure.*
Further remarks			

G1 Suspected Acute Small Bowel Obstruction

In a patient presenting with suspected bowel obstruction, the diagnostic approach depends on the clinical presentation and the suspected level of obstruction.

If acute small bowel obstruction is suspected, CT with IV contrast (oral contrast usually is avoided) is the imaging modality of choice. Plain radiography (supine or erect AXR and erect CXR) is also useful for the initial assessment. A barium small bowel series is an acceptable alternative imaging procedure after x-ray if CT is not available.

Imaging	Modality	RRL	Comments
Recommendation	*CT*	☢☢☢	*90-96% sensitive for the detection of acute high-grade obstruction.*
	AXR, CXR	☢	
	Barium study	☢☢	
Further remarks			

G2 Blunt Abdominal Trauma

For an adult patient with blunt abdominal trauma (or major trauma to chest, abdomen and pelvis AND excluding penetrating trauma) the appropriate imaging approach depends on hemodynamic stability.

In a haemodynamically stable patient, CT with IV contrast is the imaging modality of choice. Most centers do not use oral contrast for the initial evaluation (Diercks et al 2011). In an unstable patient, the most appropriate management depends on local resources and expertise.

Imaging	Modality	RRL	Comments
Recommendation	*CT*	☢☢☢	*Radiography and US may not be required if Multi Detector CT (MDCT) with multiplanar reformation is used.*
Further remarks			

G3 Dysphagia

Dysphagia may be due to a functional or structural abnormality. In a patient with dysphagia, the diagnostic approach is multi-disciplinary. Imaging and endoscopy have different strengths and weaknesses, and are complementary to each other. Further, the choice depends on the type, i.e. stricture or dysmotility as well as the level of dysphagia, i.e. oropharyngeal or retrosternal.

The imaging modality of choice is a barium swallow, preferably with video fluoroscopy. Barium swallow with video fluoroscopy will demonstrate a pharyngeal pouch, an esophageal web or motility disorders not detected by endoscopy.

Imaging	Modality	RRL	Comments
Recommendation	*Barium swallow*	☢☢	*Using a marshmallow or bolus technique better shows subtle stricture.*
Further remarks			

G4 Acute Pancreatitis

The diagnosis of acute pancreatitis is usually made clinically and biochemically. Imaging is required to determine the etiology, assess severity of disease and to detect and monitor complications.

The imaging modalities of choice are ultrasound and IV contrast-enhanced CT. Ultrasound is recommended early to assess biliary status (gall stones, duct obstruction). CT is primarily indicated when ultrasound is not diagnostic, in severe pancreatitis or in patients with deteriorating condition despite appropriate treatment.

Imaging	Modality	RRL	Comments
Recommendation	*Ultrasound*	*Nil*	
	CT	☢☢☢	
Further remarks			

G5 Acute Cholecystitis

A patient with acute cholecystitis presents with right upper quadrant pain and a positive Murphy's sign. However, about one third of patients with a clinical diagnosis of acute cholecystitis prove to have an alternative aetiology. Imaging is therefore indicated to confirm the diagnosis and rule out causes other than gallbladder disease.

The imaging modality of choice is ultrasound. If the ultrasound is normal, a nuclear medicine HIDA scan can help to confirm the diagnosis of acute cholecystitis.

Imaging	Modality	RRL	Comments
Recommendation	*Ultrasound*	*Nil*	
	NM HIDA scan	☢☢☢	*If the ultrasound is normal, a HIDA scan can help to confirm the diagnosis of acute cholecystitis.*
Further remarks			

G6 Suspected Intra-abdominal Abscess

In a patient with a suspected intra-abdominal abscess, imaging is required to make a quick and accurate diagnosis, since a timely diagnosis improves patient outcome by early intervention. The diagnostic approach may vary according to patient's clinical status, e.g. post-operative case.

The imaging modalities of choice are ultrasound and CT with IV and oral contrast. Ultrasound is the initial investigation of choice in many circumstances (e.g. suspected liver abscess, subphrenic or pelvic collections or for patients in ICU and not suitable to be transported to the CT suite). CT is the best imaging modality for the diagnosis and assessment of intra-abdominal abscess and is the initial investigation of choice in post-operative patients, as it is not limited by intervening bowel gas or body mass.

Imaging	Modality	RRL	Comments
Recommendation	*Ultrasound*	*Nil*	*Often initially used and may be definitive, particularly when there are localizing signs.*
	CT	☢☢☢	
Further remarks			

G7 Cholestatic Jaundice

In a patient with cholestatic (obstructive) jaundice, the major role of imaging is to determine the site and cause of obstruction.

Ultrasound is the initial imaging modality of choice. It can reliably differentiate obstructive from non-obstructive jaundice. Magnetic resonance cholangiopancreatography (MRCP) is indicated when ultrasound is equivocal or unsatisfactory or is used to further assess a patient with ultrasound-proven obstructive jaundice, i.e. to evaluate mass lesions in the porta hepatis or pancreas. If MR is not available, CT can be used for better evaluation of suspected tumours.

Imaging	Modality	RRL	Comments
Recommendation	*Ultrasound*	*Nil*	*Bile duct dilatation may be subtle in early obstruction.*
	MRCP	*Nil*	*MRCP if available, is the best imaging modality when ultrasound is equivocal or when further evaluation is required.*
	CT	☢☢☢	
Further remarks			

U1 Acute Scrotal Pain

In a patient presenting with acute scrotal pain, not associated with trauma or an antecedent mass, imaging is useful, especially if there is clinical doubt as to the cause of the pain and in cases not responding to treatment. Testicular torsion can frequently be diagnosed clinically and imaging should not delay surgical exploration.

The imaging modality of choice is ultrasound with Color Doppler.

Imaging	Modality	RRL	Comments
Recommendation	*Colour Doppler Ultrasound*	*Nil*	*Colour Doppler US has a high sensitivity in suspected testicular torsion but there are still false negative results.*
Further remarks			

U2 Suspected Renal Colic

In a patient presenting with acute flank pain, imaging is performed to confirm stone disease.

The imaging modality of choice is Multi Detector CT (MDCT) without IV contrast, i.e. CT urography (CTU), preferably with a low radiation dose protocol. If a calculus is identified, x-ray of the abdomen can be performed to determine if it is visible for follow-up. Intravenous urography (IVU) is indicated when MDCT is not available or CT finding is indeterminate. Ultrasound is used when CT is not indicated, e.g. young patient or pregnancy. Because of the cumulative radiation dose from CTU, consideration should be given to other forms of imaging such as x-ray and ultrasound for the follow up of patients with multiple stones.

Imaging	Modality	RRL	Comments
Recommendation	*CTU*	☢☢☢	
	AXR	☢	*Can be used for follow-up if a calculus is visible.*
Other options	*IVU*	☢☢	*Used when CTU is not available or finding is indeterminate.*
	Ultrasound	*Nil*	*If CT is contraindicated.*
Further remarks			

U3 Renal Failure

In a patient with renal failure (acute, or acute on chronic), imaging is indicated to ascertain the cause, e.g. obstructive versus non-obstructive, and to assess the renal size and morphology, i.e. parenchymal thickness.

The imaging modality of choice is ultrasound. Ultrasound is used to differentiate potentially reversible acute renal disease from chronic end-stage renal disease. It is used to assess the size of the kidneys, dilatation of the collecting systems, renal calculi and cystic diseases. Bilateral small kidneys imply irreversible chronic renal failure. Colour Doppler ultrasound provides an assessment of arterial supply and venous drainage.

Imaging	Modality	RRL	Comments
Recommendation	*Ultrasound*	*Nil*	
	NM renal scan	☢☢☢	*If ultrasound is non-diagnostic, a nuclear medicine renal scan may provide useful information about overall and differential renal function.*
Further remarks			

OG1 Post Menopausal Bleeding

In a patient with postmenopausal bleeding, imaging is indicated to assess endometrial morphology and to guide further patient management.

Imaging modality of choice is transvaginal ultrasound (TVUS).

Imaging	Modality	RRL	Comments
Recommendation	*Transvaginal ultrasound*	*Nil*	
Further remarks			

OG2 Suspected Ectopic Pregnancy

In a patient with suspected ectopic pregnancy (first trimester bleeding with acute pelvic pain or pelvic mass with positive serum beta HCG), imaging is indicated. A patient with a past history of ectopic pregnancy, pelvic inflammatory disease, infertility or tubal surgery is at an increased risk of an ectopic pregnancy.

The imaging modality of choice is ultrasound: transvaginal (TVUS) and transabdominal (TAUS). TVUS should be used wherever possible. TAUS is recommended when uterine and adnexal structures are beyond the field of the transvaginal probe. A beta HCG level >6,500 IU/L for TAUS or >1,500 IU/L for TVUS together with the absence of an intrauterine gestational sac are diagnostic of ectopic pregnancy unless proven otherwise.

Imaging	Modality	RRL	Comments
Recommendation	*Transvaginal ultrasound*	*Nil*	
	Transabdominal ultrasound	*Nil*	*When uterine and adnexal structures are beyond the field of the transvaginal probe*
Further remarks			

B1 Palpable Breast Mass or Suspected Cancer (Patient >35 years)

In a patient aged 35 years or more with a palpable breast mass or in whom breast cancer is suspected, mammography followed by ultrasound is the imaging protocol of choice. The 'Triple Assessment' of these patients includes physical examination, imaging and fine needle aspiration cytology. However, when histology is available a core biopsy may be as useful or more useful for diagnosis and prognosis than fine needle aspiration.

Imaging	Modality	RRL	Comments
Recommendation	*Mammography*	☢☢	
	Ultrasound	*Nil*	
Further remarks			

B2 Palpable Breast Mass or Suspected Cancer (Patient <35 years)

In a patient younger than 35 years with a palpable breast mass or in whom breast cancer is suspected, ultrasound is the investigation of choice. The 'Triple Assessment' of these patients includes physical examination, imaging with ultrasound and fine needle aspiration cytology.

Imaging	Modality	RRL	Comments
Recommendation	*Ultrasound*	*Nil*	
Further remarks			

P1 Developmental Dysplasia of the Hip

Imaging is not required if the clinical findings are conclusive for developmental dysplasia of the hip (DDH). If imaging is required, in a child of age less than 4 months, with suspected DDH, the investigation of choice is ultrasound. However, ultrasound is only reliable if there is local expertise. Between 4 and 6 months of age, ultrasound or x-ray may be used, and x-ray is preferred after 6 months (AAP 2000).

Imaging	Modality	RRL	Comments
Recommendation	*Ultrasound*	*Nil*	
	X-ray	☢	
Further remarks			

P2 Urinary Tract Infection

In a child with a proven urinary tract infection (UTI), the main aim of imaging is to identify cases at risk for developing recurrent UTI, renal scarring and long-term sequelae. Though there is lack of general consensus and wide variation in policies, in general, ultrasound is the first investigation of choice (AAP 2011, NIHCE 2007). A voiding cystourethrogram (VCUG) is not indicated after an uncomplicated first UTI in a child. It is indicated for an atypical UTI, if a urethral abnormality such as posterior urethral valves is suspected in a male child or if hydronephrosis is found on ultrasound. There is controversy about whether a VCUG is required following a second uncomplicated UTI. There is also controversy about the role of nuclear medicine dimercaptosuccinic acid (DMSA) scan in the management of pediatric UTI.

Imaging	Modality	RRL	Comments
Recommendation	*Ultrasound*	*Nil*	
	VCUG	☢☢	
	NM DMSA scan	☢☢☢	*This is the best imaging modality for evaluating renal scarring.*
Further remarks			

P3 New On-set Projectile Non-bilious Vomiting

In infants with projectile non-bilious vomiting where hypertrophic pyloric stenosis (HPS) is suspected, ultrasound is the modality of choice because it avoids radiation. Ultrasound can confirm HPS, especially where the clinical findings are equivocal, if there is local expertise. If ultrasound is not available or there is no local expertise, an upper GI barium study is also a reliable imaging modality for the diagnosis of HPS.

Imaging	Modality	RRL	Comments
Recommendation	*Ultrasound*	*Nil*	
	Upper GI barium study	☢☢	
Further remarks			

P4 Head Trauma

Guidelines for head trauma are of general nature and appropriateness should be assessed for individual cases. In a child with moderate to severe head trauma, neuro-imaging is indicated. In a child with minor head trauma, guidelines like the Canadian CT Head rule (Stiell et al 2001) or the New Orleans criteria should be followed.

The imaging modality of choice is CT.

Imaging	Modality	RRL	Comments
Recommendation	*CT*	☢☢☢	*Used to exclude intracranial injury as in adults.*
Further remarks			

P5 Headache

Imaging in a child with headache but without associated neurological symptoms, signs or 'red flags'; is rarely beneficial and is not indicated. In a child with neurological symptoms, signs or 'red flags', the imaging modality of choice is either MRI or CT (Lewis et al 2002, Millichap 2011). In general, MRI is preferred since it avoids the use of ionizing radiation.

The following features may be considered as 'red flags':

- *Headaches of < 1 month onset and increasing in frequency and severity;*
- *Headaches not responding to medications;*
- *No family history of migraine;*
- *Associated with neurological findings or gait abnormalities;*
- *Associated with seizures;*
- *Associated with confusion, disorientation or vomiting;*
- *Disturbs sleep or occurs immediately on waking; or*
- *Family or past history, which predisposes to CNS lesions and clinical or laboratory findings suggestive of CNS involvement.*

Imaging	Modality	RRL	Comments
Recommendation	*MRI*	*Nil*	
	CT	☢☢☢	
Further remarks			

P6 Suspected Non-accidental Injury

Suspected physical abuse, i.e. non-accidental injury (NAI), is a difficult diagnostic problem but the clinical features are well described (NIHCE 2009). Investigation of suspected child abuse may be complex and should be multidisciplinary. Skeletal, cranial and visceral injuries may all occur. Imaging plays a major role in the detection and documentation of these physical injuries. The type and extent of imaging performed depends on the child's age, symptoms, signs and other social considerations.

In a child aged 1 year or less with possible NAI, the imaging modalities of choice are:

- *Suspected skeletal injury: skeletal survey by plain radiography;*
- *Suspected cranial injury: CT; and*
- *Suspected visceral injury: CT.*

Imaging	Modality	RRL	Comments
Recommendation	X-Ray	☢	Diagnostic yield for a full skeletal survey diminishes with age, with a greatest diagnostic yield in a child < 1 year of age. In a child > 2years of age skeletal imaging should be limited to the symptomatic sites.
	NM bone scan	☢☢☢	If the skeletal survey is normal or there are equivocal findings, a nuclear medicine bone scan can be used for further evaluation.
	CT head	☢☢☢	Indicated in infants < 6 months and in children < 2 years with a history or signs of head trauma, or who have fractures identified on a skeletal survey.
	CT chest or abdomen	☢☢☢	Indicated if chest or abdominal injuries are suspected.
	Ultrasound	Nil	May be used as an initial imaging if abdominal injuries are suspected or if CT is not available.
Further remarks			

P7 Acute Uncomplicated Sinusitis

In a child with suspected uncomplicated acute sinusitis, no imaging is indicated as in most cases, diagnosis should be clinical (AAP 2001).

Imaging	Modality	RRL	Comments
Recommendation	*Imaging is not indicated.*		
Further remarks			

Section III

List 1: References

1. *American Academy of Pediatrics (2000) Clinical practice guideline: Early detection of developmental dysplasia of the hip. Pediatrics 105:896-905*
2. *American Academy of Pediatrics (2001) Clinical practice guideline: management of sinusitis. Pediatrics 108:798-808*
3. *American Academy of Pediatrics (2011) Urinary tract infection: clinical practice guideline for the diagnosis and management of the initial UTI in febrile infants and children 2 to 24 months. Pediatrics 128:595-610*
4. *American College of Radiology (2013a) ACR Appropriateness Criteria®. Available at: http://www.acr.org/Quality-Safety/Appropriateness-Criteria. Accessed 26 December 2013*
5. *American College of Radiology (2013b) ACR Appropriateness Criteria®: Radiation dose assessment introduction. Available at: http://www.acr.org/~/media/a27a29133302408bb86888eafd460a1f.pdf Accessed 26 December 2013*
6. *Balter S, Hopewell JW, Miller DL et al (2010) Fluoroscopically guided interventional procedures: a review of radiation effects on patients' skin and hair. Radiology 254(2):326-341*
7. *Canadian Association of Radiologists (2012) Diagnostic Imaging Referral Guidelines. Canadian Association of Radiologists, Quebec http://www.car.ca/en/standards-guidelines/guidelines.aspx Accessed 26 December 2013*
8. *Dauer LT, Thornton RH, Miller DL et al. (2012) Radiation management for interventions using fluoroscopic or computed tomographic guidance during pregnancy: a joint guideline of the Society of Interventional Radiology and the Cardiovascular and Interventional Radiology Society of Europe with endorsement by the Canadian Interventional Radiology Association. J Vasc Interv Radiol 23(1):19-32*
9. *Department of Health Western Australia (2013) Diagnostic Imaging Pathways. Available at: http://www.imagingpathways.health.wa.gov.au/includes/index.html. Accessed 26 December 2013*
10. *Dewachter P, Laroche D, Mouton-Faivre C et al (2011) Immediate reactions following iodinated contrast media injection: a study of 38 cases. Eur J Radiol 77(3):495-501*
11. *Diercks DB, Mehrotra A, Nazarian DJ et al (2011) Clinical policy: critical issues in the evaluation of adult patients presenting to the emergency department with acute blunt abdominal trauma. Ann Emerg Med 57(4):387-404*
12. *Doll R, Wakeford R (1997) Risk of childhood cancer from fetal irradiation. Br J Radiol 70:130-139*
13. *European Commission (2000) Radiation Protection 118. Referral Guidelines for Imaging. Available at: http://ec.europa.eu/energy/nuclear/radioprotection/publication/doc/118_en.pdf. Accessed 26 December 2013*
14. *Frush DP, Morin R, Rehani M (2014) Monitoring of medical radiation exposure for individuals. In: Lau LS, Ng KH (ed) Radiological Safety and Quality – Paradigms in Leadership and Innovation. Springer, Dordrecht*
15. *Huda W, Ravenel JG, Scalzetti EM (2002) How do radiographic techniques affect image quality and patient doses in CT? Semin Ultrasound CT MR 23(5):411-422*
16. *International Agency for Research on Cancer (2002) IARC Handbook on Cancer Prevention Vol. 7. Available at: http://www.iarc.fr/en/publications/pdfs-online/prev/handbook7/. Accessed 26 December 2013*
17. *International Atomic Energy Agency (2011) Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards - Interim Edition. IAEA Safety Standards Series GSR Part 3 (Interim), IAEA, Vienna*
18. *International Atomic Energy Agency (2013) Radiation Protection of Patients website. Available at: https://rpop.iaea.org/RPoP/RPoP/Content/index.htm. Accessed 26 December 2013*

19. *International Commission on Radiological Protection (2007a) ICRP Publication 103. The 2007 recommendations of the International Commission on Radiological Protection. Ann ICRP 37(2-4):1-332*
20. *International Commission on Radiological Protection (2007b) ICRP Publication 105. Radiological Protection in Medicine. Ann ICRP 37(6):1-63*
21. *International Radiology Quality Network (2013) Available at: http://www.irqn.org. Accessed 26 December 2013*
22. *Kilma T, Christ A, Marana I et al (2012) Sodium chloride vs. sodium bicarbonate for the prevention of contrast medium-induced nephropathy: a randomized controlled trial. Eur Heart J Jan 33(16):2071-2079*
23. *Lau LS, Ng KH (ed) (2014) Radiological Safety and Quality – Paradigms in Leadership and Innovation. Springer, Dordrecht*
24. *Lewis DW, Ashwal S, Dahl G et al (2002) Practice parameter: Evaluation of children and adolescents with recurrent headaches: report of the Quality Standards Subcommittee of the American Academy of Neurology and the Practice Committee of the Child Neurology Society. Neurology 59(4):490-498*
25. *Mandel C, Runciman W (2014) System for reporting and analysing incidents. In: Lau LS, Ng KH (ed) Radiological Safety and Quality – Paradigms in Leadership and Innovation. Springer, Dordrecht*
26. *Matthews JD, Forsythe AV, Brady Z et al (2013) Cancer risk in 680,000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians. BMJ 346:f2360*
27. *Miglioretti DL, Johnson E, Williams A et al (2013) The use of computed tomography in pediatrics and the associated radiation exposure and estimated cancer risk, JAMA Pediatr 167(8):700-707*
28. *Miller DL, Balter S, Dixon RG et al (2012) Quality improvement guidelines for recording patient radiation dose in the medical record for fluoroscopically guided procedures J Vasc Interv Radiol 23(1):11–18*
29. *Millichap JG (2011) Role of neuroimaging in evaluation of recurrent headache. American Academyof Pediatrics Grand Rounds 26(1):1*
30. *National Institute for Health and Care Excellence (2007) CG54: Urinary tract infection in children: diagnosis, treatment and long-term management. Available at: http://publications.nice.org.uk/urinary-tract-infection-in-children-cg54/guidance. Accessed 26 December 2013*
31. *National Institute for Health and Care Excellence (2009) CG89: When to suspect child maltreatment. Available at: http://guidance.nice.org.uk/CG89. Accessed 26 December 2013*
32. *Pearce MS, Salotti JA, Little MP et al. (2012) Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study. Lancet 390(9840):499-505*
33. *Royal Australian and New Zealand College of Radiologists (2001) Imaging Guidelines. 4th edn. Royal Australian and New Zealand College of Radiologists, Sydney.*
34. *Royal College of Radiologists (2007). Making the best use of clinical radiology services. 6th edn. Royal College of Radiologists, London*
35. *Royal College of Radiologists (2011). iRefer: Making the best use of clinical radiology. 7th edn. Royal College of Radiologists, London. Available to members at: http://www.rcr.ac.uk/publications.aspx?PageID=310&PublicationID=362. Accessed 26 December 2013*
36. *Seuri R, Rehani MM, Kortesniemi M (2013) How tracking radiologic procedures and dose helps: experience From Finland. Am J Roentgenol 200(4):771-775*
37. *Sharp C, Shrimptom JA, Bury RF (1998) Diagnostic medical exposures: Advice on exposure to ionizing radiation during pregnancy. National Radiological Protection Board, College of Radiographers, Royal College of Radiologists, Oxon*

38. *Stiell IG, Wells GA, Vandemheen K et al (2001) The Canadian CT Head Rule for patients with minor head injury. Lancet. 357:1391-1396*
39. *United Nations Scientific Committee on the Effects of Atomic Radiation (2010) Annex A: Medical Radiation Exposures. In: Sources and effects of ionizing radiation. UNSCEAR 2008 Report to the General Assembly. United Nations, New York*
40. *United Nations Scientific Committee on the Effects of Atomic Radiation (2013) Volume II Scientific Annex B: Effects of radiation exposure of children. In: Sources, effects and risks of ionizing radiation. UNSCEAR 2013 Report to the General Assembly. United Nations, New York*
41. *Wakeford R, Little MP, Kendall GM (2010) Risk of childhood leukemia after low-level exposure to ionizing radiation. Expert Rev Hematol 3(3):251-254*
42. *World Health Organization (1990) Effective choices for diagnostic imaging in clinical practice: Report of a WHO Scientific Group, Technical report series 795. World Health Organization, Geneva.*
43. *World Health Organization (2008) WHO Global Initiative on Radiation Safety in Health care Settings Technical Meeting Report. World Health Organization, Geneva*
44. *Zaraca F, Wiedermann CJ Ebner H (2011) Contrast media-induced nephropathy in patients undergoing angiography prior to or during vascular surgery: a systematic review. Minerva Chir 66(6):553-560*

List 2: Abbreviations

AAA	*Abdominal aortic aneurysm*
AAPM	*American Association of Physicists in Medicine*
ACR	*American College of Radiology*
AEC	*Automatic Exposure Control*
AIDS	*Acquired immune deficiency syndrome*
BPH	*Benign prostate hyperplasia*
BSS	*Basic Safety Standards*
COPD	*Chronic obstructive pulmonary disease*
CT	*Computed tomography*
CTA	*CT angiography*
CTU	*CT urography*
CVA	*Cardiovascular accident*
CXR	*Chest x-ray*
DMSA	*Dimercaptosuccinic acid*
DR	*Digital radiology*
DRL	*Diagnostic reference level*
DSA	*Digital subtraction angiography*
DVT	*Deep venous thrombosis*
EBM	*Evidence-based medicine*
EC	*European Commission*
ERCP	*Endoscopic retrograde cholangiopancreatography*
ESR	*Erythrocyte sedimentation rate*
EU	*European Union*
GMP	*Good Medical Practice*
GP	*General Practitioner*
hCG	*Human chorionic gonadotropin*
HIDA	*Hepatic 2,6-dimethyl iminodiacetic acid*
HIS	*Hospital Information System*
HRCT	*High-resolution CT*
HU	*Hounsfield unit*
IAEA	*International Atomic Energy Agency*
IARC	*International Agency for Research on Cancer*
ICRP	*International Commission on Radiation Protection*
IR	*Ionizing Radiation*
IRQN	*International Radiology Quality Network*
ISO	*International Organization for Standardization*
ISR	*International Society of Radiology*
ISRRT	*International Society of Radiographers and Radiological Technologists*
IUGR	*Intrauterine growth retardation*
IV	*Intravenous*
IVC	*Inferior vena cava*
IVP	*Intravenous pyelogram*
IVU	*Intravenous urogram*
KUB	*Kidney, ureters, blabber*

MDCT	*Multi-Detector computed tomography*
MIBG	*Metaiodobenzylguanidine*
MoH	*Ministry of Health*
MR	*Magnetic resonance*
MRA	*Magnetic resonance angiography*
MRCP	*Magnetic resonance cholangiopancreatography*
MRI	*Magnetic resonance imaging*
NCRP	*National Council on Radiation Protection & Measurements (US)*
NM	*Nuclear medicine*
NPH	*Normal pressure hydrocephalus*
PACS	*Picture Archiving and Communication Systems*
PE	*Pulmonary embolism*
PET	*Positron emission tomography*
QA	*Quality assurance*
QC	*Quality control*
QI	*Quality improvement*
QM	*Quality management*
RCR	*Royal College of Radiology*
RIS	*Radiology Information System*
ROI	*Region of interest*
RP	*Radiation Protection*
RPoP	*Radiological protection of patients*
RRL	*Relative radiation level*
RSNA	*Radiological Society of North America*
SAH	*Subarachnoid haemorrhage*
SD	*Standard deviation*
SMA	*Superior mesenteric artery*
SMV	*Superior mesenteric vein*
SPECT	*Single photon emission computed tomography*
SVC	*Superior vena cava*
TB	*Tuberculosis*
TIA	*Transient ischaemic attack*
TN	*True negative*
TP	*True positive*
TURP	*Transurethral resection of prostate*
UK	*United Kingdom*
UN	*United Nations*
UNSCEAR	*United Nations Scientific Committee on the Effects of Atomic Radiation*
US	*Ultrasound*
USA	*United States of America*
UTI	*Urinary tract infection*
UVJ	*Ureterovesical junction*
VCUG	*Voiding cystourethrography*
V/Q	*Ventilation perfusion*
WFNMB	*World Federation of Nuclear Medicine and Biology*
WFUMB	*World Federation for Ultrasound in Medicine and Biology*
WHO	*World Health Organization*

List 3: WHO / IRQN Referral Guidelines Project: Collaborators and Observers

Project Collaborators and Observers
Collaborators:
African Society of Radiology
American College of Radiology
Asian Oceanian Society of Radiology
Argentine Society of Radiology
Autorité de Sûreté Nucléaire
Canadian Association of Radiologists
Centre National de Radioprotection, Tunisia
Chinese Society of Radiology
European Commission
Federal Office for Radiation Protection, Germany
Hong Kong College of Radiologists
Inter-American College of Radiology
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Institute of Tropical Medicine, Nagasaki University
International Atomic Energy Agency
International Commission on Radiological Protection
International Paediatric Association
International Radiology Quality Network
International Society of Radiology
International Society of Radiographers and Radiological Technologists
Israeli Centre for Technology Assessment in Health Care, Ministry of Health
Médecins Sans Frontières
Pan Arab Association of Radiological Societies
National Centre for Child Health and Development, Japan
National Centre of Radiobiology and Radiation Protection, Bulgaria
Pan American Health Organization
Radiological Society of North America
Royal and Australian New Zealand College of Radiologists
World Federation of Nuclear Medicine and Biology
World Federation of Ultrasound in Medicine and Biology
World Health Organization
World Organization of National Colleges, Academies and Academic Associations of General Practitioners and Family Physicians
Observers:
European Society of Radiology
French Society of Radiology
Royal College of Radiologists

List 4: WHO Referral Guidelines for Appropriate Use of Radiation Imaging Consultancy Participants

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