EUROPEAN GUIDELINES

ON QUALITY CRITERIA

FOR COMPUTED TOMOGRAPHY

EUR 16262

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These Guidelines result from the cooperative effort of the following European Study Group of radiologists and physicists involved in diagnostic computed tomography and consultation with experts in the field:

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QUALITY CRITERIA FOR COMPUTED TOMOGRAPHY

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PREAMBLE

Computed Tomography (CT) was introduced into clinical practice in 1972 and revolutionised x-ray imaging by providing high quality images which reproduced transverse cross sections of the body. The technique offered in particular improved low contrast resolution for better visualization of soft tissue, but with relatively high absorbed radiation dose. The initial potential of the imaging modality has been realised by rapid technological developments, resulting in a continuing expansion of CT practice. **As a result, the numbers of examinations are increasing to the extent that CT has made a substantial impact on not only patient care but also patient and population exposure from medical x-rays.** Today it accounts for up to 40% of the resultant collective dose from diagnostic radiology in some countries of the European Union (EU) (1,2). Special measures are consequently required to ensure optimisation of performance in CT, and of patient protection.

In comparison with conventional radiology, the relative complexity, range and flexibility of scanner settings in CT may adversely affect the levels of image quality and patient dose achieved in practice. There is, therefore, a need to establish quality criteria for CT which will provide the required clinical information in its optimal form, with minimum dose to the patient.

The quality criteria concept, as developed for conventional x-ray examinations of adult and paediatric patients by the European Commission's (EC) research actions, has proved to be an effective method for optimising the use of ionising radiation in medical imaging procedures. The purpose of quality criteria for CT was therefore also to provide an operational framework for radiation protection initiatives for this modality, in which technical parameters required for image quality are considered in relation to patient dose.

CT continues to evolve and the research base for guidance is limited. The study group on "Development of Quality Criteria for CT" has drawn extensively on the results of the projects carried out in the EC's Research Action on Optimisation of Radiation Protection of the Patient. It has also gained inspiration from the guidelines of the German Federal Chamber of Physicians on Quality Assurance in Computed Tomography (3). The primary working document of April 1997 has been commented on by external experts from countries in Europe and was presented at the EC workshop on reference dose and quality in medical imaging, October 1997, Luxembourg (4). A revised document dated May 1998 was posted on the Internet (http://www.drs.dk/CT/document/) and advertised to all national delegates of the European Association of Radiology (EAR) and the European Federation of Organisations for Medical Physics (EFOMP), in addition to the European National Boards of Health and the associations of radiographers. A notification was also given to these bodies of a Workshop on Quality Criteria for Computed Tomography that was held in Aarhus, Denmark, 13-14th November 1998. The document was open for discussion at the workshop and consequently revised to the present final guidelines. Furthermore, the study group performed a pilot study in 1997-1998 to test the image quality criteria, with simultaneous registration of the radiation dose, for five types of examination: 1) face and sinuses, 2) vertebral trauma, 3) HRCT of the lung, 4) liver and spleen and 5) osseous pelvis (5). The results have been taken into account in the final guidelines, including the specification of diagnostic reference dose values.

These guidelines on Quality Criteria for Computed Tomography provide guidance on the definition and introduction of quality criteria for diagnostic images and equipment performance, as well as for dose to the patient. The report contains four chapters.

The first chapter presents general principles associated with good imaging technique and lists the Quality Criteria for six groups of CT examination: cranium, face and neck, spine, chest, abdomen and pelvis, and bones and joints. Each group of examinations is subdivided into the most common examinations of specific organs or parts of the body. The chapter defines Diagnostic Requirements by specifying anatomical image criteria; indicates Criteria for the Radiation Dose to the Patient; and gives Examples of Good Imaging Technique by which the Diagnostic Requirements and Dose Criteria can be achieved.

The second chapter summarises available research results as well as the ongoing experiments

which have supported the establishment of the Quality Criteria listed in Chapter 1, and suggests directions for future research.

The third chapter outlines a procedure for implementing and auditing the Quality Criteria and a model for image quality assessment.

The fourth chapter contains a glossary of terms used in the guidelines.

This initiative in CT will continue within the framework of forthcoming research programmes and is reflected by the Council Directive on health protection of individuals against dangers of ionising radiation in relation to medical exposure (6). For techniques such as CT the new Directive requires the establishment of quality assurance measures which include criteria that can be employed and checked in a comparable way so that the radiation dose to the patient can be linked to the required image quality and to the performance of the chosen technique.

Emerging techniques such as multislice CT and fluoro-CT have not been specifically addressed. With the continuing evolution of CT technology there will be a need for regular updating of the guidelines.

It is the hope of the European Commission's services that the elaboration of the Quality Criteria for CT will stimulate the professionals concerned to look for improvements in the criteria in such a way that day-to-day practice achieves optimal diagnostic information and fulfils at the same time the requirements for optimization of radiation protection in the 1997 Council Directive.

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1. Kaul A, Bauer B, Bernhardt J, Noske D and Veit R. Effective doses to members of the public from the diagnostic application of ionizing radiation in Germany. European Radiology **7**, 1127 - 1132 (1997)

2. Shrimpton PC and Edyvean S. CT scanner dosimetry. British Journal of Radiology **71**, 1 - 3 (1998)

3. Leitlinien der Bundesärztekammer zur Qualitätssicherung in der Computertomographie. Dt. Ärztebl. **89**: Heft 49 (1992) (English translation: Guidelines of the Federal Chamber of Physicians on quality assurrence in computed tomography. Internal Document CEC XII/354/92-EN)

4. Bauer B, Corbett RH, Morres BH, Schibilla H and Teunen D (Eds). Proceedings of a Workshop on Reference Doses and Quality in Medical Imaging, Luxembourg, October 23-25 1997. Radiation Protection Dosimetry **80**, Nos 1-3 (1998)

5. Jurik AG, Petersen J, Bongartz B, Golding SJ, Leonardi M, van Meerten PvE, Geleijns J, Jessen KA, Panzer W, Shrimpton P, Tosi G. Clinical use of image quality criteria in computed tomography related to radiation dose. A pilot study. European Radiology (to be submitted)

6. Council Directive 97/43/EURATOM of 30 June 1997 on health protection of individuals against the dangers of ionizing radiation in relation to medical exposure. Official Journal

L 180, p. 22, 9.7.1997. (Repealing Directive 84/466/EURATOM, O.J. no. L265, p. 1, 5.10.1984)

Chapter 1

QUALITY CRITERIA FOR COMPUTED TOMOGRAPHY

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Technical terms are defined in the Glossary (Chapter 4) and are printed in italics when they are used for the first time in these guidelines.

INTRODUCTION

The two basic principles of radiation protection for medical exposures as recommended by ICRP are justification of practice and optimisation of protection, including the consideration of *diagnostic reference level*s (1, 2, 3). The emphasis is to keep dose to the patient as low as reasonably achievable (ALARA), consistent with clinical requirements. These principles are largely translated into a legal framework by the Council Directive (4).

Justification is the first step in radiation protection and no diagnostic exposure is justifiable without a valid clinical indication. Every examination must result in a net benefit for the patient. This will be the case when it can be anticipated that the examination will influence the efficacy of clinical decisions made with respect to the following:

- diagnosis
- patient management and therapy
- final outcome for the patient

Justification for computed tomography (CT) also implies that the required result cannot be achieved by other methods which are associated with lower risks for the patient. Ultrasound and MRI offer alternatives to CT in many areas of application.

The magnitude of the absorbed dose in CT means that particular care is required for the examination of pregnant women, children, and particularly sensitive organs or tissues. Criteria for approving clinical requests in these circumstances need to be particularly stringent.

As a corollary, justification requires that the imaging procedure is acceptably reliable, i.e. its results are reproducible and have sufficient predictive value with respect to the particular clinical question.

Justification also necessitates that a suitably qualified person (as recognised by the competent authority), usually a radiologist, approves the need for CT and takes overall clinical responsibility for the examination. This person should work in close contact with the referring physician in order to establish the investigation procedure most appropriate to patient management. The person responsible may authorize an appropriately qualified operator (eg radiographer or medical radiation technologist) to perform the examination.

In respect of radiological examinations, ICRP draws attention to the use of diagnostic reference levels as an aid to optimisation of protection in medical exposure. Once the diagnostic examination has been clinically justified, the subsequent imaging process must be optimised. The optimal use of ionising radiation involves the interplay of three important aspects of the imaging process:

- diagnostic quality of the image
- radiation dose to the patient
- choice of examination technique

This document provides guidance on all three of these aspects for a number of selected CT examinations, as an example of an achievable standard of day-to-day practice. **The Quality Criteria presented define a level of performance considered necessary to produce images of standard quality for a particular anatomical region.**

For comparability, the aim has been to establish Guidelines on Quality Criteria for CT in accordance with the structure of the existing "European Guidelines for Diagnostic Radiographic Images" for adult and paediatric patients in conventional radiology (5, 6).

OBJECTIVES

The objectives of the guidelines are to achieve:

- adequate image quality, comparable throughout Europe

- reasonably low radiation dose per examination

The guidelines also provide a basis for accurate radiological interpretation of the image.

The guidelines are directed primarily at clinical and technical staff who perform CT and report on it. They will also be of interest to those responsible for the design of CT equipment and for the maintenance of its function. They will be helpful to those who have responsibility for equipment specification and purchase.

The guidelines represent an achievable standard of good practice which may be used as a basis for further development by the radiological community.

In support of these objectives, the guidelines provide structured advice on the following key areas:

Diagnostic Requirements

The diagnostic requirements are presented as image criteria, which in CT are basically of two different types: anatomical and physical image criteria. The anatomical image criteria include requirements which must be fulfilled when specific clinical questions are posed. These criteria may be defined in terms of **visualization** or **critical reproduction** of anatomical features (see Description of Terms, p.12). Evaluation of image quality based on anatomical criteria takes into account both the anatomy of the area under examination and the contrast between different tissues which is essential for the detection of pathological changes.

The physical image criteria are measurable by objective means. They include *noise; low contrast resolution; spatial resolution; linearity; uniformity and stability* of the CT numbers; *slice thickness* and dose. It is mandatory for departments carrying out CT to employ a suitable quality assurance programme to maintain imaging performance at optimal levels. Routine tests have to specify physical image criteria.

Criteria for Radiation Dose to the Patient

Consideration of dose constraint has particular importance in CT, since this is recognised as a relatively high dose modality. ICRP (1) has recommended the dose constraint concept for medical exposure, that is translated to diagnostic reference levels for diagnostic radiography (3). The application of this concept is in line with the reference dose values for a standard sized patient indicated in the previous European Guidelines (5, 6). In the present guidelines tentative reference dose values for CT have been established for selected examinations in order to facilitate comparison of examination protocols used in different departments and with different types of equipment. The reference dose values are based on *dose descriptors* defined in Appendix 1. More detailed discussion of dosimetry is given in Chapter 2.

Diagnostic reference dose values provide quantitative guidance to help identify relatively poor or inadequate use of the technique rather than an indication of satisfactory performance.

Further dose reduction below reference values may be achievable without compromising the diagnostic value of an individual examination, and this should always be pursued.

Examples of Good Imaging Technique

Image quality in CT depends primarily on two types of scan parameter: dose-related parameters and those which are related to processing and viewing of the image. Both are hardware related. Dose-related parameters are the slice thickness, *inter-slice distance, pitch factor, volume of investigation, exposure factors and gantry tilt.* Processing parameters are *field of view*, *number of measurements*, *reconstruction matrix* size, *reconstruction algorithm* and *window settings* for viewing the image. Impact of these parameters on image quality and patient dose can be assessed quantitatively by measurement with *test phantoms*, which provide information essential to the definition of quality criteria related to the clinical objective.

GENERAL PRINCIPLES ASSOCIATED WITH GOOD IMAGING TECHNIQUE: TECHNICAL, CLINICAL AND PHYSICAL PARAMETERS

CT images are the result of the interplay of physical phenomena giving rise to *attenuation* by the patient of a thin fan beam of x-rays, and complex technical procedures. Each image consists of a matrix of *pixels* whose CT numbers (measured in Hounsfield Units, *HU*) represent attenuation values for the volume elements (*voxels*) within the slice. The quality of the image relates to the fidelity of the CT numbers and to the accurate reproduction of small differences in attenuation (low contrast resolution) and fine detail (spatial resolution). Good imaging performance demands that image quality should be sufficient to meet the clinical requirement for the examination, whilst maintaining the dose to the patient at the lowest level that is reasonably practicable. In order to achieve this, there must be careful selection of technical parameters that control exposure of the patient and the display of the images, and also regular checking of scanner performance with measurement of physical image parameters as part of a programme of quality assurance.

1. Technical Parameters: Display and Exposure Parameters with an Influence on Image Quality and Dose

1.1 Nominal slice thickness

The nominal slice thickness in *CT* is defined as the *full width at half maximum* (FWHM) of the *sensitivity profile*, in the centre of the scan field; its value can be selected by the operator according to the clinical requirement and generally lies in the range between 1mm and 10mm. In general, the larger the slice thickness, the greater the low contrast resolution in the image; the smaller the slice thickness, the greater the spatial resolution. If the slice thickness is large, the images can be affected by *artefact*, due to *partial volume effects*; if the slice thickness is small (e.g. 1-2mm), the images may be significantly affected by noise.

1.2 Inter-slice distance/pitch factor

Inter-slice distance is defined as the *couch increment* minus nominal slice thickness. In helical CT the pitch factor is the ratio of the couch increment per rotation to the nominal slice thickness at the axis of rotation. In clinical practice the inter-slice distance generally lies in the range between 0 and 10mm, and the pitch factor between 1 and 2. The inter-slice distance can be negative for overlapping scans which in helical CT means a pitch < 1. In general, for a constant volume of investigation, the smaller the inter-slice distance or pitch factor, the higher both the local dose and the integral dose to the patient. The increase in the local dose is due to superimposition of the *dose profile*s of the adjacent slices. The increase in the integral dose is due to an increase in the volume of tissue undergoing direct irradiation as indicated by a *packing factor.*

In those cases where 3D reconstruction or reformatting of the images in coronal, sagittal or oblique planes is required, it is necessary to reduce the inter-slice distance to zero or perform a helical scan. In screening or examinations performed with regard to control of disease it can be diagnostically justifiable to have an inter-slice distance corresponding to half the slice thickness or a pitch factor of 1.5-2.

1.3 Volume of investigation

Volume of investigation, or imaging volume, is the whole volume of the region under examination. It is defined by the outermost margins of the first and last examined slices or helical exposure. The extent of the volume of investigation depends on the clinical needs; in general the greater its value the higher the integral dose to the patient, unless an increased inter-slice distance or pitch factor is used.

1.4 Exposure factors

Exposure factors are defined as the settings of x-ray tube voltage (kV), tube current (mA) and *exposure time* (s). In general, one to three values of tube voltage (in the range between 80 and 140 kV) can be selected. A high tube voltage is recommended for high

resolution CT (HRCT) of the lungs and may be used for examination of osseous structures such as the spine, pelvis and shoulder. Soft tissue structures are usually best visualised using the standard tube voltage for the given equipment. In some cases of *quantitative computed tomography* (QCT), the same *slice* is examined with two different values of tube voltage, in order to subtract corresponding images and derive information about the composition of particular tissues. At given values of tube voltage and slice thickness, the image quality depends on the product of x-ray tube current (mA) and exposure time (s), expressed in mAs. Absolute values of mAs necessary for an imaging task will depend on the type of scanner and the patient size and composition. For a particular CT model, an increase in *radiographic exposure* setting (mAs) is accompanied by a proportional increase in the dose to the patient. Relatively high values of radiographic exposure setting (mAs) should therefore be selected only in those cases where a high *signal to noise ratio* is indispensable.

A method for correlating the exposure setting (for a given tube voltage) with the overall image quality is by drawing contrast-detail curves for each available setting. These curves express the minimum size of detail which can still be recognised in the CT image for a given difference in contrast between the detail and the surrounding medium.

1.5 Field of view

Field of view (FOV) is defined as the maximum diameter of the reconstructed image. Its value can be selected by the operator and generally lies in the range between 12 and 50 cm. The choice of a small FOV allows increased spatial resolution in the image, because the whole reconstruction matrix is used for a smaller region than is the case with a larger FOV; this results in reduction of the pixel size. In any case, the selection of the FOV must take into account not only the opportunity for increasing the spatial resolution but also the need for examining all the areas of possible disease. If the FOV is too small, relevant areas may be excluded from the visible image. If *raw data* are available the FOV can be changed by post-processing.

1.6 Gantry tilt

Gantry tilt is defined as the angle between the vertical plane and the plane containing the x-ray tube, the x-ray beam and the *detector array*. Its value normally lies in the range between -25° and +25°. The degree of gantry tilt is chosen in each case according to the clinical objective. It may also be used to reduce the radiation dose to sensitive organs or tissues and/or to reduce or eliminate artefacts.

1.7 Reconstruction matrix

Reconstruction matrix is the array of rows and columns of pixels in the reconstructed image, typically 512 x 512.

1.8 Reconstruction algorithm

Reconstruction algorithm (*filter*, or *kernel*) is defined as the mathematical procedure used for the *convolution* of the attenuation profiles and the consequent reconstruction of the CT image. In most CT scanners, several reconstruction algorithms are available. The appearance and the characteristics of the CT image depend strongly on the algorithm selected. Most CT scanners have special soft tissue or standard algorithms for examination of the head, abdomen etc. Depending on clinical requirements, it may be necessary to select a high resolution algorithm which provides greater spatial resolution, for detailed representation of bone and other regions of high natural contrast such as pulmonary parenchyma.

1.9 Window width

Window width is defined as the range of CT numbers converted into grey levels and displayed on the image monitor. It is expressed in HU. The window width can be selected by the operator according to the clinical requirements, in order to produce an image from which the clinical information may be easily extracted. In general, a large window (for instance 400 HU) represents a good choice for acceptable representation of a wide range

of tissues. Narrower window widths adjusted to diagnostic requirements are necessary to display details of specific tissues with acceptable accuracy.

1.10 Window level

Window level is expressed in HU and is defined as the central value of the window used for the display of the reconstructed CT image. It should be selected by the viewer according to the attenuation characteristics of the structure under examination.

2. Clinical and Associated Performance Parameters

A series of clinical factors play a special part in the optimal use of ionising radiation in CT. They are described here in order to ensure that an appropriate CT examination is carried out, providing diagnostic quality with a reasonable radiation dose for the patient.

A CT examination should therefore only be carried out on the basis of a justifiable clinical indication, and exposure of the patient should always be limited to the minimum necessary to meet clinical objectives.

Adequate clinical information, including the records of previous imaging investigations, must be available to the person approving requests for CT.

In certain applications, in order to practice CT effectively, prior investigation of the patient by other forms of imaging might be required.

2.1 Supervision

CT examinations should be performed under the clinical responsibility of a radiologist/practitioner according to the regulations (4) and *standard examination* protocols should be available.

Effective supervision may support radiation protection of the patient by terminating the examination when the clinical requirement has been satisfied, or when problems occurring during the examination (for example, unexpected uncooperation by the patient or the discovery of contrast media residue from previous examinations) cannot be overcome.

Problems and pitfalls: the responsible radiologist/practitioner should be aware of clinical or technical problems which may interfere with image quality. Many of these are particular to specific organs or tissues and may lead to modification of technique. The radiologist/practitioner and the radiographer must be aware of manoeuvres which may be used to overcome such diagnostic or technical problems in order to provide a clinically relevant examination.

2.2 Patient Preparation

The following patient-related operational parameters play an important role for the quality of the CT examination:

2.2.1 Cooperation. Patient cooperation should be ensured as far as possible prior to the examination. An explanation of the procedure should be given to each patient. Good communication with and control of the patient is equally necessary during the whole examination.

2.2.2 Protective Shielding. Relevant protection for sensitive organs outside the imaging field is a lead-purse for the male gonads, if the edge of the volume of investigation is less than 10 - 15 cm away. The protection of female gonads by wrap-around lead has not yet been demonstrated (7,8). Appropriate protection measures must be applied to persons who, for clinical reasons or to ensure cooperation, may need to accompany patients in the examination room during the examination.

2.2.3 Clothing. The area of examination should be free of external metal or other radio-

dense items where possible. Special attention must be given to eliminating any x-ray dense material in the patient's clothes or hair.

2.2.4 Fasting. Fasting prior to the examination is not essential. Restraint from food, but not fluid, is recommended if intravenous contrast media are to be given.

2.2.5 Intravenous contrast media. These are needed in some examinations and must be employed in a manner appropriate to the clinical indication, taking into consideration the risk factors.

2.2.6 Oral or cavitatory contrast media. Oral contrast medium may be required in abdomino-pelvic examinations and must be administered at times and in doses appropriate to the indication. Administration of contrast medium per rectum may be required in some examinations of the pelvis and a vaginal tampon should be used in some examinations for gynaecological applications.

2.2.7 Positioning and motion. Most CT examinations are carried out with the patient supine. In this position the patient is most comfortable with the knees flexed. Alternate positioning may be required to aid comfort and cooperation, for appropriate display of anatomy, to reduce absorbed radiation to particular organs, or to minimise artefact. Motion should be kept to a minimum to reduce artefacts; typical sources of artefacts are involuntary patient movement, respiration, cardiovascular action, peristalsis and swallowing.

2.3 Examination Technique

- Scan projection radiograph.
  A *scan projection radiograph* permits the examination to be planned and controlled accurately, and provides a record of the location of images. It is recommended that this is performed in all cases. In general such imaging provides only a small fraction of the total patient dose during a complete CT procedure (9)

- Clinical aspects of setting the appropriate technical parameters.
  These parameters must be set according to the area of examination and clinical indication, as follows:

  * Nominal slice thickness is chosen according to the size of the anatomical structure or lesion that needs to be visualised. Staff should be aware of the implications of choice of slice thickness in relation to the image quality and radiation dose to the patient.

  * Inter-slice distance is chosen according to the area under examination and the clinical indication. Staff should be aware of the risk of overlooking lesions which fall in the inter-slice interval during serial CT. **In general, the interval should not exceed one half of the diameter of suspected lesions.** This problem is absent in helical *scanning*, when an appropriate reconstruction index is used.

  * Field of view (FOV). Selection of FOV must respect image resolution and the need to examine all areas of possible disease. If the FOV is too small, disease may be excluded from the visible image.

  * Exposure factors: tube voltage (kV), tube current (mA) and exposure time (s) affect image quality and patient dose. Increasing exposure increases low contrast resolution by reducing noise but also increases patient dose. Patient size is an important factor in determining the image noise. Image quality consistent with the clinical indications should be achieved with the lowest possible dose to the patient. In certain examinations image noise is a critical issue and higher doses might be required.

* The volume of investigation is the imaging volume, defined by the beginning and end of the region imaged. It should cover all regions of possible disease for the particular indication.

* Reconstruction algorithm: this is set according to the indication and area under examination. For most examinations, images are displayed utilising algorithms suitable for soft tissues; other algorithms available include those providing greater spatial resolution for detailed display of bone and other areas of high natural contrast.

2.4 Helical or Spiral CT

Helical or spiral CT is obtained by continuous tube rotation coupled with continuous patient transport through the gantry, resulting in volumetric data acquisition. Due to the high speed and ease of image performance with this technique it should be emphasized that helical CT presents particular challenges in radiation protection and it should not be used without clinical justification. Helical CT is in most cases preferable to serial CT because of **advantages** such as:

- a possibility of dose saving:

  * the repeating of single scans, which sometimes results from lack of patient cooperation in serial CT, is reduced in spiral CT because of the shorter examination times involved
  * for pitch > 1 the dose will be reduced compared with contiguous serial scanning; there are no data missing as may be the case with the use of an inter-slice interval in serial CT
  * the practice of using overlapping scans or thin slices in serial CT for high quality 3D display or multi-planar reconstructions is replaced by the possibility of reconstructing overlapping images from one helical scan volume data set

- extremely shortened examination time:

  * makes it possible to acquire continuous patient data during a single breath-hold; problems with inconsistent respiration can thereby be avoided
  * disturbances due to involuntary movements such as peristalsis and cardiovascular action are reduced
  * may optimize scanning with the use of intravenous contrast media (10,11)

- images can be reconstructed for any couch position in the volume of investigation:

  * anatomical misregistration is avoided
  * equivocal lesions can be further evaluated without additional patient exposure
  * the possibility of displaying the data volume in transverse slices reconstructed at intervals smaller than the x-ray beam *collimation* results in overlapping slices which, in combination with reduced or eliminated movement artefacts, makes it possible to perform high quality three-dimensional (3D) and multi planar reconstructions with smooth tissue contours. This is used especially in skeletal (12) and vascular imaging (CT angiography) (10).

Helical CT, however, has **drawbacks** such as:

- ease of performance may tempt the operator to extend the examination unjustifiably, either by increasing the imaging volume, or by repeated exposure of a region

- although most image quality parameters are equivalent for contiguous serial CT and helical CT performed with a pitch = 1 (13,14), the performance of helical CT with a pitch greater than 1.5 may imply lower and possibly insufficient diagnostic image quality due to reduced low contrast resolution (10,14)

- spatial resolution in the z-direction is lower than indicated by the nominal slice width (13,15) unless special *interpolation* is performed (15)

- the technique has inherent artefact

When using helical CT in conjunction with intravenous injection of contrast media to provide optimally enhanced images, careful timing of exposure relative to intravenous injection is mandatory.

2.5 Image viewing conditions

It is recommended that initial reading of CT images is carried out from the TV monitor. Display of images and post-processing image reconstruction should be at a *display matrix* of at least 512 x 512.

Brightness and contrast control on the viewing monitor should be set to give a uniform progression of the grey scale from black to white. A calibrated grey-scale would be preferable.

Settings of window width and window level dictate the visible contrast between tissues and should generally be chosen to give optimum contrast between normal structures and lesions.

2.6 Film Processing

Optimal processing of the film has important implications for the diagnostic quality of the image stored on film. Film processors should be maintained at their optimum operating conditions as determined by the manufacturer and by regular and frequent quality control procedures.

3. Physical Parameters: Physical Measures of Scanner Performance.

The quality of the CT image may be expressed in terms of physical parameters such as uniformity, linearity, spatial resolution, low contrast resolution and absence of artefacts according to IEC recommendations (16). It depends on the technological characteristics of the CT scanner, the exposure factors used and image viewing conditions. Quality may be assessed by quantitative measurement of the parameters listed above, using suitable test phantoms, and by the appearance of artefacts. These measurements should be conducted regularly, in order to guarantee the maintenance of performance of the CT scanner during its whole period of use. It is essential that such technical quality control has been performed when using the criteria presented in these guidelines.

3.1 Test Phantoms

Test phantoms (phantom of a standardised human shape or test objects of a particular shape, size and structure) are used for the purposes of *calibration* and evaluation of the performance of CT scanners. Performance is checked by acceptance tests after installation and important repairs, and by periodic quality control tests, as established in standardised protocols. A number of test phantoms are commercially available and most manufacturers provide one or more test objects.

The test phantoms should allow for the following parameters to be checked: mean CT number, uniformity, noise, spatial resolution, slice thickness, dose and positioning of couch (16).

3.2 CT Number

The accuracy of CT number is verified by scanning a test object utilising the usual operating parameters and reconstruction algorithms. The CT number is affected by the x-ray tube voltage, beam filtration and object thickness. The CT number of water is by definition equal to 0 HU and the mean CT number measured over the central *region of interest* (ROI) should be in the range +/- 4HU.

3.3 Linearity

Linearity concerns the linear relationship between the calculated CT number and the *linear attenuation coefficient* of each element of the object. It is essential for the correct evaluation of a CT image and, in particular, for the accuracy of QCT. Deviations from linearity should not exceed +/- 5HU over specific ranges (soft tissue or bone).

3.4 Uniformity

Uniformity relates to the requirement for the CT number of each pixel in the image of a homogeneous object to be the same within narrow limits over various regions of the object such as a cylindrical 20 cm diameter phantom of water-equivalent plastic. The difference in the mean CT number between a peripheral and a central region of a homogeneous test object should be $\leq$8HU. Such differences are largely due to the physical phenomenon of *beam hardening.*

3.5 Noise

Picture element (pixel) or image noise is the local statistical fluctuation in the CT numbers of individual picture elements of a homogeneous ROI. Noise is dependent on the radiation dose and has a marked effect on low contrast resolution. The magnitude of the noise is indicated by the standard deviation of the CT numbers over a ROI in a homogeneous substance. It should be measured over an area of about 10% of the cross-sectional area of the test object. Image noise diminishes with the use of a slightly flattened convolution kernel, with simultaneous reduction of spatial resolution and an increase in low contrast resolution. Image noise is inversely proportional to the square root of the dose and to the slice thickness. For example, if the dose is halved then the noise will only increase by about 40%. Conversely, a reduction in slice thickness requires a proportionate increase in dose in order to avoid an increase in noise. The medical problem under study and the corresponding image quality required should determine what level of image noise and what patient dose are reasonably practicable.

3.6 Spatial Resolution

Spatial resolution at high and low contrast are interdependent and critical to image quality and good imaging of diagnostically important structures.

The spatial resolution at high contrast (*high contrast resolution*) determines the minimum size of detail visualised in the plane of the slice with a contrast $\geq$10%. It is affected by the reconstruction algorithm, the *detector width*, the slice thickness, the object to detector distance, the x-ray tube *focal spot* size, and the matrix size.

The spatial resolution at low contrast (low contrast resolution) determines the size of detail that can be visibly reproduced when there is only a small difference in density relative to the surrounding area. Low contrast resolution is considerably limited by noise. The perception threshold in relation to contrast and detail size can be determined, for example, by means of a contrast-detail curve. In such determinations, the effects of the reconstruction algorithm and of the other scanning parameters have to be known. Dose and the corresponding image noise greatly affect low contrast resolution.

3.7 Slice Thickness

The slice thickness is determined in the centre of the field of view as the distance between the two points on the sensitivity profile along the axis of rotation at which response has fallen to 50%. Certain deviations in thickness should not be exceeded because of the effect of slice thickness on image detail; for example, with a nominal slice thickness $\geq$8mm, a maximum deviation of ± 10% is acceptable; tolerable deviations for smaller slice thickness of 2-8 mm and < 2 mm are ± 25% and ± 50%, respectively.

The use of post-patient collimation, which is inherent in some CT equipment to reduce the slice sensitivity profile, leads to significant increases in the patient dose for a series of contiguous slices (9).

3.8 Stability of CT numbers

Stability is defined as the maintenance over time of constancy of CT number and of uniformity. It can be checked by means of a suitable test object, containing at least three specimens of different materials, e.g. water, *Polymethylmethacrylate (PMMA)* and Teflon. Deviations should not exceed +/- 5 CT numbers with respect to initial mean values. A similar tolerance should be applied in the verification of uniformity, as measured in three ROI's, each containing approximately 100 pixels and placed respectively at the centre, at the periphery, and in a position intermediate between the centre and the periphery of the reconstructed image.

3.9 Positioning of couch

The accuracy of positioning of the patient couch is evaluated by moving the loaded couch a defined distance relative to the gantry and subsequently moving it back to the start position (16). Positional accuracy includes both deviation in longitudinal positioning and also backlash. Maximum tolerances of ±2 mm apply to both criteria. These also apply to mobile CT equipment.

GUIDANCE ON IMPLEMENTATION

Quality Criteria are presented for a number of selected CT examinations. They apply to adult patients of standard size (~70kg mass and ~170cm height) undergoing usual application of the technique for the type of examination under consideration. These Quality Criteria are to be used by radiologists, operators and medical physicists as a check on the routine performance of the entire imaging process. The Quality Criteria are helpful for the immediate checking of the quality of imaging performance while the patient is still in the scanner.

However, the Quality Criteria cannot be applied to all cases. For certain clinical indications a lower level of image quality may be acceptable but this should always be associated with a lower radiation dose to the patient.

For each selected CT examination certain preparatory steps are necessary to ensure full justification and accurate control of the examination: - Indications, - Advisable preliminary investigations, - Patient preparation and - Scan projection radiograph. These will be given at the top of the List of Quality Criteria for each type of examination. The Quality Criteria are divided into the following three parts that are generally characteristic for the CT procedures, in addition to a fourth part which takes into account special clinical conditions:

1. DIAGNOSTIC REQUIREMENTS

   These list image criteria which specify important anatomical structures that should be visible in the image to aid accurate diagnosis. A qualitative guide to the necessary degree of visibility of these essential structures is provided in the following Description of Terms.

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

   Reference dose values are provided as far as available, in relation to technique for a standard-sized patient for each type of CT examination considered. These quantities are defined in Appendix 1 to Chapter 1 and discussed in detail in Chapter 2.

3. EXAMPLE OF GOOD IMAGING TECHNIQUE

   This section provides examples of CT technique parameters which facilitate good imaging performance that is capable of meeting all the above Quality Criteria. If radiologists and operators find that Diagnostic Requirements or Criteria for Radiation Dose to the Patient are not met, then the Example of Good Imaging Technique can be used as a guide to how their technique might be improved.

4. CLINICAL CONDITIONS WITH IMPACT ON IMAGING PERFORMANCE

A number of conditions due to patient behaviour and technical particularities are listed which require special awareness and intervention of the operator.

DESCRIPTION OF TERMS USED IN THE LISTS OF QUALITY CRITERIA

1. DIAGNOSTIC REQUIREMENTS

The listed **image criteria** refer to characteristic features of imaged anatomical structures that are defined in the region of examination with a specific degree of visibility. At the present time there are no internationally accepted definitions. For the purpose of these guidelines the degree of visibility is defined as follows:

1.1 **Visualization** - The organs and structures are detectable in the volume of investigation.

1.2 **Critical reproduction** - The structures particular to the specific indication are discriminated to a level essential for diagnosis. This will include the terms:

- **reproduction** - details of anatomical structures are visible but not necessarily clearly defined.

- **visually sharp reproduction** - anatomical details are clearly defined.

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

Diagnostic reference dose values are indicated for two dose descriptors *weighted CT DI* ($CTDI_W$) and *dose-length product* (DLP) on the basis of absorbed dose to air, in relation to technique for a standard-sized patient.

2.1 $CTDI_w$ is the approximation of average dose over a single slice in the standard head or body *CT dosimetry phantom*, expressed in terms of absorbed dose to air (mGy).

2.2 DLP characterises exposure for a complete examination in relation to linear integration of the dose to the standard head or body CT dosimetry phantom on the basis of absorbed dose to air (mGy cm).

2.3 Comparison of $CTDI_w$ or DLP values for a particular type of procedure provides a useful indication of relative performance. However, data for examinations on different regions of the body can not be compared directly in order to assess relative patient risk.

Appendix 1 to Chapter 1 gives further information concerning the definition of these quantities and methods to check compliance with the dose criteria. The derivation of the diagnostic reference dose values and additional background information is given in Chapter 2.

3. EXAMPLE OF GOOD IMAGING TECHNIQUE

Parameters are listed that contribute to the fulfilment of the Diagnostic Requirements and the Criteria for Radiation Dose to the Patient.

3.1 **Patient position**

3.2 **Volume of investigation** - anatomical landmarks for beginning and end of the scan.

3.3 **Nominal slice thickness for serial or collimation for helical CT** - in mm.

3.4 **Inter-slice distance/pitch** - in mm/factor.

3.5 **Field of View (FOV)** - maximum diameter (in cm) of the reconstructed image.

3.6 **Gantry tilt** - angle (°) between vertical plane and plane containing the x-ray tube, the x-ray scan beam and the detector array.

3.7 **X-ray tube voltage** - in kV. This should, if possible, be selected so as to achieve the required image quality at lowest practicable dose.

3.8 **Tube current and exposure time product** - in mAs. Selection of tube current (mA) and exposure time (s) to determine radiographic exposure (mAs) is of critical importance. Absolute values of mAs cannot be recommended in view of significant differences in operating characteristics between types of scanner. Operators should be aware of the characteristics particular to their scanner and understand the range of settings that are consistent with meeting required image quality and reference dose values.

3.9 **Reconstruction algorithm** - broad type of mathematical filter for the reconstruction of the CT image.

3.10 **Window width** - in HU. Range of CT numbers converted into grey levels and displayed on the image monitor.

3.11 **Window level** - in HU. Central value of the window used for the display of the reconstructed CT image.

3.12 **Protective shielding** - additional protection devices to reduce exposure of sensitive organs and tissues.

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

Motion - patient or organ movements.

Problems and pitfalls - mostly site specific clinical or technical problems which impede image quality.

Modification of technique - in order to provide clinically relevant examination in case of technical or diagnostic problems.

LIST OF QUALITY CRITERIA FOR COMPUTED TOMOGRAPHY

BRAIN, GENERAL

Preparatory steps:

- Indications: traumatic lesions, and suspected or known focal or diffuse structural disease of the brain when MRI is contraindicated or not available

- Advisable preliminary investigations: clinical neurological examination; MRI is often an alternative examination without exposure to ionizing radiation

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: lateral from skull base to vertex; in patients with multiple injuries from cervical vertebra to vertex

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of
1.1.1 Whole cerebrum
1.1.2 Whole cerebellum
1.1.3 Whole skull base
1.1.4 Vessels after intravenous contrast media

1.2 Critical reproduction
1.2.1 Visually sharp reproduction of the border between white and grey matter
1.2.2 Visually sharp reproduction of the basal ganglia
1.2.3 Visually sharp reproduction of the ventricular system
1.2.4 Visually sharp reproduction of the cerebrospinal fluid space around the mesencephalon
1.2.5 Visually sharp reproduction of the cerebrospinal fluid space over the brain
1.2.6 Visually sharp reproduction of the great vessels and the choroid plexuses after intravenous contrast media

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	routine head: 60 mGy
2.2	DLP	:	routine head: 1050 mGy cm

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine
3.2	Volume of investigation	:	from foramen magnum to the skull vertex
3.3	Nominal slice thickness	:	2-5 mm in posterior fossa; 5-10 mm in hemispheres
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0
3.5	FOV	:	head dimension (about 24 cm)
3.6	Gantry tilt	:	10-12° above the orbito-meatal (OM) line to reduce exposure of the eye lenses

3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue
3.10	Window width	:	0-90 HU (supratentorial brain) 140-160 HU (brain in posterior fossa) 2000-3000 HU (bones)
3.11	Window level	:	40-45 HU (supratentorial brain) 30-40 HU (brain in posterior fossa) 200-400 HU (bones)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates image quality (prevented by head fixation or sedation of non-cooperative patients)
4.2	Intravenous contrast media	-	useful to identify vascular structures, enhancing lesions and alterations of blood-brain barrier
4.3	Problems and pitfalls	- -	calcifications versus *contrast enhancement* interpetrous beam hardening artefacts
4.4	Modification to technique	-	subtle irregularity can be checked with slices in the area of suspected pathology, before considering contrast administration

SKULL BASE

Preparatory steps:

- Indications: neurological diseases (cranial nerves), trauma, malformations, metastasis and bone diseases

- Advisable preliminary investigations: x-ray examination of the skull and base may only occasionally be necessary; MRI may be an alternative examination without exposure to ionising radiation

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: lateral from C2 to skull vertex

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of

1.1.1 Entire skull base from C1 to the suprasellar region
1.1.2 Entire cerebellum
1.1.3 Basal part of the frontal lobes
1.1.4 Vessels after intravenous contrast media

1.2 Critical reproduction

1.2.1 Visually sharp reproduction of the cortical and trabecular bone structures
1.2.2 Visually sharp reproduction of the air filled compartments
1.2.3 Visually sharp reproduction of the sella turcica
1.2.4 Visually sharp reproduction of the cerebellar contours
1.2.5 Reproduction of the border between the white and grey matter (cerebellum)
1.2.6 Visually sharp reproduction of the cerebrospinal fluid space around the brain stem
1.2.7 Visually sharp reproduction of the great vessels and choroid plexuses after intravenous contrast media

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine head: 60 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine head: 1050 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine
3.2	Volume of investigation	:	from C1 to the suprasellar region
3.3	Nominal slice thickness	:	2-5 mm
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0
3.5	FOV	:	head dimension (about 24 cm)
3.5	Gantry tilt	:	OM line

3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	high resolution or soft tissue/standard
3.10	Window width	:	2000-3000 HU (bones) 70-90 HU (supratentorial brain) 100-160 HU (brain in posterior fossa)
3.11	Window level	:	200-400 HU (bones) 40-45 HU (supratentorial brain) 30-40 HU (brain in posterior fossa)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	- movement artefact deteriorates image quality (prevented by head fixation or sedation of non-cooperative patients)
4.2	Intravenous contrast media	- useful to identify vascular structures, enhancing lesions and alterations of blood-brain barrier
4.3	Problems and pitfalls	- calcifications versus contrast enhancement - interpetrous beam hardening artefacts
4.4	Modification to technique	- subtle irregularity can be checked with slices in the area of suspected pathology, before considering contrast administration - higher mAs may be required if artefacts degrade the image quality in the posterior fossa

FACE AND SINUSES

Preparatory steps:

- Indications: trauma, malformations, malignancies and inflammation

- Advisable preliminary investigations: appropriate x-ray examination of the face except for isolated evaluation of the sinuses; MRI may be an alternative examination, especially in malignancies

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: lateral from jaw to vertex

1. DIAGNOSTIC REQUIREMENTS

Image criteria

1.1 Visualization of
1.1.1 Entire face from palate to the top of the frontal sinus
1.1.2 Vessels after intravenous contrast media

1.2 Critical reproduction
1.2.1 Visually sharp reproduction of the cortical and trabecular bone structures
1.2.2 Visually sharp reproduction of the frontal sinuses
1.2.3 Visually sharp reproduction of the sphenoid sinuses
1.2.4 Visually sharp reproduction of the orbitae
1.2.5 Reproduction of the globe, optic nerve and orbital muscles
1.2.6 Visually sharp reproduction of the ethmoid
1.2.7 Visually sharp reproduction of the maxilla and its sinuses
1.2.8 Visually sharp reproduction of the nasal cavity
1.2.9 Visually sharp reproduction of the rhinopharynx

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	35 mGy (pilot study (17))
2.2	DLP	:	360 mGy cm (pilot study)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine for axial scans; supine or prone for coronal scans
3.2	Volume of investigation	:	from palate to the top of the frontal sinus
3.3	Nominal slice thickness	:	3-5 mm. Helical CT is preferable for evaluation of the face
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0; 1-2 mm or a pitch up to 1.2 - 1.5 may be used in screening examinations of the sinuses
3.5	FOV	:	head dimension (about 24 cm)
3.6	Gantry tilt	:	0 to -10° from OM for axial scanning of the

			face; according to the patient position for coronal scanning
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	high resolution or standard
3.10	Window width	:	1500-3000 HU (bones) 140-1000 HU (soft tissue)
3.11	Window level	:	200-400 HU (bones) 30-100 HU (soft tissue)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates image quality (prevented by head fixation or sedation of non-cooperative patients)
4.2	Intravenous contrast media	-	useful to identify vascular structures and enhancing lesions
4.3	Problems and pitfalls	-	artefacts from teeth or dental prothesis/fillings
4.4	Modification to technique	-	change of gantry angulation or patient position to avoid artefact
		-	examination of the sinuses in a prone position to keep inflammatory secretion away from the osteomeatal complex
		-	examination of the sinuses preliminary to functional endoscopic sinus surgery is best performed directly in the coronal plane

PETROUS BONE

Preparatory steps:

- Indications: hearing deficits, inflammation, vertigo, facial or acoustic nerve diseases, malformations, bone diseases and trauma

- Advisable preliminary investigations: examination of acoustic and labyrinth function, evoked potentials; appropriate x-ray examination of skull, base and petrous bone may only occasionally be necessary; MRI may be an alternative examination without exposure to ionising radiation

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: lateral from mastoid to above skull base

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of

1.1.1 Entire petrous bone
1.1.2 Vessels after intravenous contrast media

1.2 Critical reproduction

1.2.1 Visually sharp reproduction of the cortical and trabecular bone structures
1.2.2 Visually sharp reproduction of the bone structures of the temporal bone such as the cochlea: ossicular chain, fenestra ovale, facial canal and labyrinth
1.2.3 Visually sharp reproduction of the air filled compartments
1.2.4 Visually sharp reproduction of the adjacent cerebellum
1.2.5 Visually sharp reproduction of the adjacent cerebrum
1.2.6 Reproduction of border between the white and grey matter
1.2.7 Visually sharp reproduction of the great vessels and choroid plexuses after intravenous contrast media

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine head: 60 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine head: 1050 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine, for axial scans; supine or prone for coronal scans
3.2	Volume of investigation	:	from 0.5 cm below to 0.5 cm above the petrous bone
3.3	Nominal slice thickness	:	1-3 mm
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0
3.5	FOV	:	head dimension (about 24 cm); secondary

			reduction of FOV is necessary for evaluation of subtle pathology
3.6	Gantry tilt	:	OM line or tilted above OM line for axial scanning; according to the patient position for coronal scanning
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	high resolution or standard
3.10	Window width	:	2000-3000 HU (bones) 140-160 HU (soft tissue) 1500-2500 HU (middle setting)
3.11	Window level	:	200-400 HU (bones) 30-40 HU (soft tissue) 150-250 HU (middle setting)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	- movement artefact deteriorates image quality (prevented by head fixation or sedation of non-cooperative patients)
4.2	Intravenous contrast media	- useful to identify vascular structures and enhancing lesions
4.3	Problems and pitfalls	- calcifications versus contrast enhancement - interpetrous bone hardening artefacts
4.4	Modification to technique	- subtle irregularity can be checked with slices in the area of suspected pathology, before considering contrast administration - higher mAs may be required if artefacts degrade the image quality in the posterior fossa - coronal scans may be used to reduce artefacts - intrathecal contrast may be useful to detect small accustic neuromas

ORBITS

Preparatory steps:

- Indications: structural diseases of the orbits and orbital content, trauma, foreign body

- Advisable preliminary investigations: evaluation of visual function; evoked potentials; appropriate x-ray examination of the orbits may occasionally be necessary; MRI and ultrasonography may be alternative examinations without exposure to ionising radiation

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: lateral from jaw to vertex

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of
1.1.1 Entire orbits
1.1.2 Osseous walls
1.1.3 Vessels after intravenous contrast media

1.2 Critical reproduction
1.2.1 Visually sharp reproduction of the osseous walls
1.2.2 Visually sharp reproduction of the optic nerve canal
1.2.3 Visually sharp reproduction of the globe
1.2.4 Visually sharp reproduction of the optic nerve
1.2.5 Visually sharp reproduction of the orbital muscles
1.2.6 Visually sharp reproduction of the retrobulbar fat
1.2.7 Visually sharp reproduction of the main vessels after intravenous contrast media

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine head: 60 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine head: 1050 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine for axial scans; supine or prone for coronal scans
3.2	Volume of investigation	:	from 0.5 cm below to 0.5 cm above the orbital cavity
3.3	Nominal slice thickness	:	2-5 mm
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0
3.5	FOV	:	head dimension (about 24 cm); secondary reduction of FOV is necessary for evaluation of subtle pathology

3.6	Gantry tilt	:	-6 to -10° from OM or parallel to the optic nerve for axial scanning; according to the patient position for coronal scanning
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	high resolution or standard
3.10	Window width	:	140-300 HU (soft tissue) 2000-3000 HU (bones) about 4000 HU (special orbit window)
3.11	Window level	:	30-40 HU (soft tissue) 200-400 HU (bones) about 0 HU (special orbit window)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates image quality (prevented by head fixation or sedation of non-cooperative patients)
4.2	Intravenous contrast media	-	useful to identify vascular structures and enhancing lesions
4.3	Problems and pitfalls	-	calcifications versus contrast enhancement
		-	foreign bodies (beam hardening artefacts)
		-	artefacts from orbital or dental prothesis/fillings
4.4	Modification to technique	-	change of gantry angulation or patient position to avoid artefact

SELLA AND HYPOPHYSIS

Preparatory steps:

- Indications: suspicion of sellar or hypophyseal alterations (endocrinological diseases, visual defects, alterations of ocular motility) when MRI is contra-indicated or not available. MRI is the examination of choice

- Advisable preliminary investigations: evaluation of visual function

- Patient preparation: information about the procedure: restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: lateral from C2 to above skull base

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of
1.1.1 Entire hypophyseal region including osseous walls
1.1.2 Vessels after intravenous contrast media

1.2 Critical reproduction
1.2.1 Visually sharp reproduction the osseous limit of the sella
1.2.2 Visually sharp reproduction of the hypophysis and its stalk
1.2.3 Reproduction of intrahypophyseal density differences
1.2.4 Visually sharp reproduction of the chiasm and suprasellar cisterns
1.2.5 Visually sharp reproduction of the cavernous sinuses and lateral sellar regions
1.2.6 Visually sharp reproduction of the main vessels after intravenous contrast media

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information:routine head: 60 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine head: 1050 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine for axial scans; supine or prone for coronal scans
3.2	Volume of investigation	:	from 0.5 cm below to 0.5 cm above the hypophyseal region
3.3	Nominal slice thickness	:	2-3 mm
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0
3.5	FOV	:	head dimension (about 24 cm); secondary reduction of FOV is necessary for evaluation of subtle pathology
3.6	Gantry tilt	:	OM line for axial scanning; according to the patient position for coronal scanning

3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue or high resolution
3.10	Window width	:	140-300 HU (soft tissue) 2000-3000 HU (bones)
3.11	Window level	:	30-40 HU (soft tissue) 200-400 HU (bones)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates image quality (prevented by head fixation or sedation of non-cooperative patients)
4.2	Intravenous contrast media	-	useful to identify vascular structures, enhancing lesions and alterations of blood-brain barrier
4.3	Problems and pitfalls	- - -	calcifications versus contrast enhancement foreign bodies (beam hardening artefacts) artefacts from dental prothesis/fillings
4.4	Modification to technique	-	change of gantry angulation or patient position to avoid artefact

SALIVARY GLANDS (PAROTID AND SUBMANDIBULAR)

Preparatory steps:

- Indications: lateral facial mass; recurrent parotid or submandibular swelling; T/N staging of salivary gland neoplasms

- Advisable preliminary investigations: radiography if calculus is suspected; ultrasonography or MRI may be alternative examinations without exposure to ionising radiation

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal from orbital region to glottis

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of
1.1.1 Entire parotid gland
1.1.2 Entire submandibular gland
1.1.3 Overlaying subcutaneous fat and skin
1.1.4 Regional lymph node territories (in cases of neoplasm)
1.1.5 Vessels after intravenous contrast media

1.2 Critical reproduction
1.2.1 Visually sharp reproduction of the glandular tissue
1.2.2 Visually sharp reproduction of the margins of normal glands
1.2.3 Visually sharp reproduction of the paraglandular fat spaces
1.2.4 Visually sharp reproduction of regional lymph node areas
1.2.5 Reproduction of the mandible and associated muscles

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine head: 60 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine head: 1050 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine
3.2	Volume of investigation	:	parotid: from external ear to angle of jaw; submandibular gland: from dorsum of tongue to hyoid bone; from external ear to glottis if detection of lymphadenopathy is required
3.3	Nominal slice thickness	:	3-5 mm
3.4	Inter-slice distance/pitch	:	contiguous, but for large lesions distances of <3-5 mm or a pitch up to 1.5 - 2.0 may be used
3.5	FOV	:	adjusted to the minimum required to

			demonstrate complete cross section of the face. Reduction of FOV may be necessary for the evaluation of subtle pathologies
3.6	Gantry tilt	:	none
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue/standard or if necessary high resolution
3.10	Window width	:	250-500 HU
3.11	Window level	:	0-30 HU (unenhanced examination) 30-60 HU (enhanced examination)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates the image quality (prevented by quiet respiration; swallowing should be suspended during exposure but encouraged between exposures to avoid salivary pooling)
4.2	Intravenous contrast media	-	may be required to distinguish lymphadenopathy and blood vessels
		-	for better definition of lesions
		-	for demonstrating involvement of cranium by neoplasms
4.3	Problems and pitfalls	-	artefact from dental prothesis/fillings
		-	movement artefact due to swallowing
		-	submandibular lymphadenopathy may mimic enlarged submandibular glands
4.4	Modification to technique	-	extension of the examination to the cranium to demonstrate relationship of disease to the base of the skull and the parapharyngeal space
		-	change of gantry angulation or patient position to avoid artefact

PHARYNX

Preparatory steps:

- Indications: diagnosis of parapharyngeal masses; T/N staging of pharyngeal neoplasms

- Advisable preliminary investigations: endoscopy may be performed; MRI and ultrasonography may be alternative examinations without exposure to ionising radiation, ultrasonography especially with regard to surrounding structures

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: lateral from orbital roof to root of neck

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of
1.1.1 Entire pharynx
1.1.2 Regional lymph node areas and associated muscles
1.1.3 Base of the skull
1.1.4 Oesophagopharyngeal junction
1.1.5 Vessels after intravenous contrast media

1.2 Critical reproduction
1.2.1 Reproduction of the wall of pharynx throughout the area of examination
1.2.2 Visually sharp reproduction of the mucosal margin
1.2.3 Visually sharp reproduction of the parapharyngeal fat spaces
1.2.4 Visually sharp reproduction of the parapharyngeal muscles
1.2.5 Visually sharp reproduction of regional lymph node areas

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine head: 60 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine head: 1050 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine
3.2	Volume of investigation	:	nasopharynx: from sphenoid bone to hyoid bone and continue to root of the neck for N-staging of neoplasms; oropharynx/hypopharynx: from palate to root of the neck
3.3	Nominal slice thickness	:	3-5 mm serial or preferably helical
3.4	Inter-slice distance/pitch	:	contiguous, but for large lesions distances of <3-5 mm or a pitch up to 1.5 - 2 may be used

3.5	FOV	:	adjusted to the minimum required to demonstrate complete cross section of the face. Reduction of FOV may be necessary for the evaluation of subtle pathologies
3.6	Gantry tilt	:	none
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with image quality
3.9	Reconstruction algorithm	:	soft tissue/standard or if necessary high resolution
3.10	Window width	:	300-500 HU
3.11	Window level	:	0-30 HU (unenhanced examination) 30-60 HU (enhanced examination)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	- movement artefact deteriorates the image quality (swallowing should be suspended during exposure but encouraged between exposures to avoid salivary pooling)
4.2	Intravenous contrast media	- may be required to improve contrast between normal and abnormal tissues or characterize some parapharyngeal lesions - routinely required if invasion of the base of the skull is suspected
4.3	Problems and pitfalls	- artefact from dental prothesis/fillings - apposition of the pharyngeal mucosal folds may obscure pathology - pooling of saliva may mimic pathology - superficial mucosal extent of neoplasms may not be identified - secretion from oropharyngeal neoplasms
4.4	Modification to technique	- coronal sections for demonstrating the relationship of disease to the skull base - exposure with open mouth or with oral Valsava to open nasopharyngeal folds - change of gantry angulation or patient position to avoid artefact

LARYNX

Preparatory steps:

- Indications: T/N staging of neoplasm; evaluation of congenital or post-traumatic abnormalities of airway

- Advisable preliminary investigations: MRI and ultrasonography may be alternative examinations without exposure to ionising radiation

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: lateral from floor of mouth to thoracic inlet

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of

1.1.1 Entire larynx
1.1.2 Paralaryngeal tissues, including muscles, blood vessels and the thyroid gland
1.1.3 Regional lymph node areas
1.1.4 Spine and paravertebral muscles.
1.1.5 Vessels after intravenous contrast media

1.2 Critical reproduction

1.2.1 Reproduction of the wall of the larynx throughout the area of examination
1.2.2 Visually sharp reproduction of the mucosal folds
1.2.3 Visually sharp reproduction of the perimucosal fat spaces
1.2.4 Visually sharp reproduction of the intrinsic pharyngeal muscles
1.2.5 Visually sharp reproduction of the paralaryngeal muscles
1.2.6 Visually sharp reproduction of regional lymph node areas

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine head: 60 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine head: 1050 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine
3.2	Volume of investigation	:	from base of tongue to root of neck
3.3	Nominal slice thickness	:	3-5 mm serial or preferably helical CT, especially in patients having difficulties with salivary pooling
3.4	Inter-slice distance/pitch	:	contiguous, but for large lesions distances of <3-5 mm or a pitch up to 1.5 - 2.0 may be used
3.5	FOV	:	adjusted to the minimum required to demonstrate complete cross section of the

			neck. Reduction of FOV may be necessary for the evaluation of subtle pathologies
3.5	Gantry tilt	:	none or modified parallel to the line of vocal folds on scan projection radiograph
3.6	X-ray tube voltage (kV)	:	standard
3.7	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.8	Reconstruction algorithm	:	soft tissue/standard or if necessary high resolution
3.9	Window width	:	250-500 HU
3.10	Window level	:	0-30 HU (unenhanced examination) 30-60 HU (enhanced examination)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates the image quality (avoided by quiet respiration; swallowing should be suspended during exposure but encouraged between exposures to avoid salivary pooling)
4.2	Intravenous contrast media	-	may be required to distinguish lymphadenopathy
		-	improves delineation of neoplasm
4.3	Problems and pitfalls	-	movement artefact due to respiration
		-	staging errors due to poor discrimination between normal and abnormal tissues
		-	salivary pooling may mimic pathology
		-	displacement of vocal fold by adjacent mass may mimic glottal involvement
4.4	Modification to technique	-	reformatted images may require thin serial slices if helical CT is not available
		-	sections through glottis may be obtained during phonation

VERTEBRAL AND PARAVERTEBRAL STRUCTURES

Preparatory steps:

- Indications: traumatic lesions and as a guide to biopsy; also structural diseases of the vertebrae, medulla and paravertebral tissues, if MRI is contraindicated or not available. MRI is the examination of choice in non-traumatic disorders

- Advisable preliminary investigations: radiography of the vertebral column, and in some patients myelography

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal or lateral of the suspected diseased region

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of

1.1.1 The entire region of suspected pathology
1.1.2 Vessels after intravenous contrast media
1.1.3 Spinal cord and nerve roots after intrathecal injection of contrast media (CT-myelography)

1.2 Critical reproduction

1.2.1 Visually sharp reproduction of the cortical and trabecular bone
1.2.2 Visually sharp reproduction of the intervertebral joints
1.2.3 Visually sharp reproduction of the intervertebral disk profiles
1.2.4 Visually sharp reproduction of the intervertebral radicular canals
1.2.5 Reproduction of the thecal sac
1.2.6 Visually sharp reproduction of the spinal cord or cauda equina (CT-myelography)
1.2.7 Reproduction of the paravertebral ligaments
1.2.8 Visually sharp reproduction of the paravertebral muscles
1.2.9 Reproduction of the main vessels and perithecal venous plexuses after intravenous contrast medium

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	70 mGy for vertebral trauma (pilot study (17))
2.2	DLP	:	460 mGy cm for vertebral trauma (pilot study)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine
3.2	Volume of investigation	:	from 1 cm above to 1 cm below the region of suspected pathology
3.3	Nominal slice thickness	:	2-5 mm
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0
3.5	FOV	:	dimension corresponding to the spine and surrounding paravertebral structures

3.6	Gantry tilt	:	none (allow easy production of reformatted images) or parallel to the intervertebral disks
3.7	X-ray tube voltage (kV)	:	standard or high kV in large persons to avoid noise
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue or high resolution
3.10	Window width	:	140-350 HU (soft tissue) 2000-3000 HU (bones) 300-400 HU (cervical spine)
3.11	Window level	:	30-40 HU (soft tissue) 200-400 HU (bones) 25-35 HU (cervical spine)
3.12	Protective shielding	:	lead-purse for the male gonads if the edge of the volume of investigation is less than 10-15 cm away

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates image quality (prevented by sedation of non-cooperative patients)
4.2	Intravenous contrast media	-	useful to identify vascular structures and enhancing lesions
4.3	Problems and pitfalls	-	foreign bodies (beam hardening artefacts)
4.4	Modification to technique	-	production of reformatted images of adequate quality may require thin serial slices if helical CT is not available

LUMBAR SPINE, DISCAL HERNIATION

Preparatory steps:

- Indications: radiculopathy (sciatica), back pain, failure of conservative treatment and postoperative back pain, especially when MRI is contra-indicated

- Advisable preliminary investigations: radiography of the spine; electromyography; MRI is a preferable alternative examination without exposure to ionising radiation

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: lateral of the suspected diseased disks

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of

1.1.1 The entire region of suspected pathology
1.1.2 Vessels after intravenous contrast media
1.1.3 Spinal cord and nerve roots after intrathecal injection of contrast media (CT-myelography)

1.2 Critical reproduction

1.2.1 Visually sharp reproduction of the intervertebral disk profiles
1.2.2 Visually sharp reproduction of the thecal sac
1.2.3 Visually sharp reproduction of the perithecal fat
1.2.4 Visually sharp reproduction of the intervertebral radicular canals
1.2.5 Visually sharp reproduction of the nerve roots
1.2.6 Reproduction of the main vessels and perithecal venous plexuses after intravenous contrast media
1.2.7 Reproduction of the cortical and trabecular bone
1.2.8 Visually sharp reproduction of the intervertebral joints
1.2.9 Reproduction of the paravertebral ligaments

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine abdomen: 35 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine abdomen: 800 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine, legs in flexion
3.2	Volume of investigation	:	from pedicle to pedicle with targeting of a slice at the centre of the suspected diseased disks
3.3	Nominal slice thickness	:	2-5 mm
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0
3.5	FOV	:	spine dimension

3.6	Gantry tilt	:	as parallel as possible to the intervertebral disc planes; a different gantry tilt may be required for each intervertebral space
3.7	X-ray tube voltage (kV)	:	standard or high kV in large persons to avoid noise
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue/standard or high resolution
3.10	Window width	:	140-400 HU (soft tissue) 2000-3000 HU (bones) 250-300 HU (lumbar spine)
3.11	Window level	:	30-40 HU (soft tissue) 200-400 HU (bones) 25-35 HU (lumbar spine)
3.12	Protective shielding	:	lead-purse for the male gonads if the edge of the volume of investigation is less than 10-15 cm away

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates image quality (prevented by sedation of non-cooperative patients)
4.2	Intravenous contrast media	-	useful to identify vascular structures and enhancing lesions
4.3	Problems and pitfalls	- -	foreign bodies (beam hardening artefacts) calcifications versus contrast enhancement
4.4	Modification to technique	-	intrathecal injection of contrast medium (CT-myelography) to delineate the spinal cord and nerve roots

Preparatory steps:

- Indications: tetraparesis, paraparesis, other neurological deficits and spinal cord compression syndrome when MRI is contra-indicated or not available. MRI is the examination of choice

- Advisable preliminary investigations: radiography of the spine and/or myelography

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal or lateral of all the suspected vertebral segments

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of

1.1.1 The entire region of suspected pathology
1.1.2 Vessels after intravenous contrast media
1.1.3 Spinal cord and nerve roots after intrathecal injection of contrast media (CT-myelography)

1.2 Critical reproduction

1.2.1 Visually sharp reproduction of spinal cord contours (CT-myelography)
1.2.2 Visually sharp reproduction of the thecal sac
1.2.3 Visually sharp reproduction of the perithecal fat
1.2.4 Visually sharp reproduction of the intervertebral disk profiles
1.2.5 Reproduction of the main vessels and perithecal venous plexuses after intravenous contrast media
1.2.6 Visually sharp reproduction of the intervertebral radicular canals
1.2.7 Visually sharp reproduction of the intervertebral joints
1.2.8 Reproduction of the paravertebral ligaments
1.2.9 Visually sharp reproduction of the paravertebral muscles

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine chest or abdomen: 30/35 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine chest or abdomen: 650/800 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine, legs in flexion
3.2	Volume of investigation	:	from 1 cm above to 1 cm below suspected pathology
3.3	Nominal slice thickness	:	2-5 mm
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0

3.5	FOV	:	spine dimension
3.6	Gantry tilt	:	none (allow easy production of reformatted images)
3.7	X-ray tube voltage (kV)	:	standard or high kV in large persons to avoid noise
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue/standard or high resolution
3.10	Window width	:	140-400 HU (soft tissue) 2000-3000 HU (bones) 250-300 HU (cervical spine) 3000-4000 HU (CT-myelography)
3.11	Window level	:	30-40 HU (soft tissue) 200-400 HU (bones) 25-35 HU (cervical spine) 400-600 HU (CT-myelography)
3.12	Protective shielding	:	lead-purse for the male gonads if the edge of the volume of investigation is less than 10-15 cm away

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates image quality (prevented by sedation of non-cooperative patients)
4.2	Intravenous contrast media	-	useful to identify vascular structures and enhancing lesions
4.3	Problems and pitfalls	- -	foreign bodies (beam hardening artefacts) calcifications versus contrast enhancement
4.4	Modification to technique	- -	intrathecal injection of contrast medium (CT-myelography) to delineate the spinal cord and nerve roots production of reformatted images of adequate quality may require thin serial slices if helical CT is not available

Preparatory steps:

- Indications: suspected or known pulmonary, pleural or lymph node disease, including metastatic neoplasms, infection, traumatic lesions and focal diseases

- Advisable preliminary investigations: chest radiography

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal from neck to upper abdomen

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of

1.1.1 Entire thoracic wall
1.1.2 Entire thoracic aorta and vena cava
1.1.3 Entire heart
1.1.4 Entire lung parenchyma
1.1.5 Vessels after intravenous contrast media

1.2 Critical reproduction

1.2.1 Visually sharp reproduction of the thoracic aorta
1.2.2 Visually sharp reproduction of the anterior mediastinal structures, including thymic residue (if present)
1.2.3 Visually sharp reproduction of the trachea and main bronchi
1.2.4 Visually sharp reproduction of the paratracheal tissue
1.2.5 Visually sharp reproduction of the carina and lymph node area
1.2.6 Visually sharp reproduction of the oesophagus
1.2.7 Visually sharp reproduction of the pleuromediastinal border
1.2.8 Visually sharp reproduction of large and medium sized pulmonary vessels
1.2.9 Visually sharp reproduction of segmental bronchi
1.2.10 Visually sharp reproduction of the lung parenchyma
1.2.11 Visually sharp reproduction of the border between the pleura and the thoracic wall

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	routine chest: 30 mGy
2.2	DLP	:	routine chest: 650 mGy cm

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine, arms above the head
3.2	Volume of investigation	:	from lung apex to the base of the lungs
3.3	Nominal slice thickness	:	7-10 mm serial or preferably helical
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0; 4-5 mm or pitch up to 1.5 may be used for large lesions or detection of lymphadenopathy alone; even larger inter-slice distance/pitch may be applied

			in critically ill patients
3.5	FOV	:	adjusted to largest thoracic diameter within the volume of investigation
3.6	Gantry tilt	:	none
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue/standard
3.10	Window width	:	300-600 HU (soft tissue) 800-1.600 HU (lung parenchyma)
3.11	Window level	:	0-30 HU (soft tissue, unenhanced examination) 30-60 HU (soft tissue, enhanced examination) ÷500-÷700 HU (lung parenchyma)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates the image quality. This is prevented by a standard breath-hold technique; alternatively if this is not possible scan during quiet respiration
4.2	Intravenous contrast media	-	may be used to characterise lesions or to distinguish them from vessels
4.3	Problems and pitfalls	-	anatomical misregistration due to variation in the phase of respiration
		-	focal atelectasis may obscure pathology
		-	motion artefact due to cardiac pulsation or respiration
4.4	Modification to technique	-	prone position may be used to elucidate pleural lesions or focal spaces
		-	the examination may be confined to a specific area of interest
		-	4 mm slices may be used for specific examination of hilar pathology and subtle pulmonary lesions

CHEST, MEDIASTINAL VESSELS

Preparatory steps:

- Indications: suspected or known major vessel aneurysm, dissection or congenital anomaly

- Advisable preliminary investigations: chest radiography, including lateral projection; MRI or transoesophageal ultrasonography may be alternative examinations without exposure to ionising radiation

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal from neck to upper abdomen

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of
1.1.1 Entire thoracic aorta
1.1.2 Entire vena cava
1.1.3 Entire heart
1.1.4 Vessels after intravenous contrast media

1.2 Critical reproduction
1.2.1 Visually sharp reproduction of the contour of the thoracic aorta
1.2.2 Visually sharp reproduction of the wall of the thoracic aorta
1.2.3 Visually sharp reproduction of the superior vena cava
1.2.4 Visually sharp reproduction of the major anterior mediastinal vessels
1.2.5 Visually sharp reproduction of the heart
1.2.6 Visually sharp reproduction of the inferior vena cava
1.2.7 Visually sharp reproduction of large and medium sized pulmonary vessels

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine chest: 30 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine chest: 650 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine, arms above the head
3.2	Volume of investigation	:	may be limited to area of radiographic abnormality or clinically suspected lesion
3.3	Nominal slice thickness	:	4-5 mm serial or preferably helical
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0; 2-4 mm or a pitch up to 1.2 - 1.5 for large lesions
3.5	FOV	:	limited to area of the heart and major vessels

3.6	Gantry tilt	:	none
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue/standard
3.10	Window width	:	100-400 HU (soft tissue, unenhanced examination) 150-500 HU (soft tissue, enhanced examination)
3.11	Window level	:	0-50 HU (soft tissue, unenhanced examination) 20-150 HU (soft tissue, enhanced examination, depends on dose and method of contrast administration)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates the image quality. This is prevented by a standard breath-hold technique; alternatively if this is not possible scan during quiet respiration
4.2	Intravenous contrast media	-	enhancement is required for many examinations
4.3	Problems and pitfalls	-	artefact from the cardiac outline may cross the aorta and mimic dissection flap - inhomogeneities in luminal opacification due to inconstant blood flow - inappropriate administration of contrast media may mimic thrombus
4.4	Modification to technique	-	not usually required

CHEST, HRCT (HIGH RESOLUTION CT)

Preparatory steps:

- Indications: detection and characterization of diffuse parenchymal lung disease including emphysema or bronchiectasis

- Advisable preliminary investigations: chest radiography and respiratory function tests

- Patient preparation: information about the procedure

- Scan projection radiograph: frontal from neck to upper abdomen

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of
1.1.1 Entire field of lung parenchyma

1.2 Critical reproduction
1.2.1 Visually sharp reproduction of the lung parenchyma
1.2.2 Visually sharp reproduction of pulmonary fissures
1.2.3 Visually sharp reproduction of secondary pulmonary lobular structures such as interlobular arteries
1.2.4 Visually sharp reproduction of large and medium sized pulmonary vessels
1.2.5 Visually sharp reproduction of small pulmonary vessels
1.2.6 Visually sharp reproduction of large and medium sized bronchi
1.2.7 Visually sharp reproduction of small bronchi
1.2.8 Visually sharp reproduction of the pleuromediastinal border
1.2.9 Visually sharp reproduction of the border between the pleura and the thoracic wall

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	35 mGy (pilot study (17))
2.2	DLP	:	280 mGy cm (pilot study)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine, arms above the head
3.2	Volume of investigation	:	from lung apex to the base of the lungs (survey) or corresponding to radiographically defined abnormality (localised disease)
3.3	Nominal slice thickness	:	1-2 mm
3.4	Interslice distance	:	10-20 mm
3.5	FOV	:	adjusted to the minimum which will demonstrate the whole lung field
3.6	Gantry tilt	:	none
3.7	X-ray tube voltage (kV)	:	high kV or standard

3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	high resolution
3.10	Window width	:	1000-1600 HU
3.11	Window level	:	÷400-÷700 HU

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	- movement artefact deteriorates the image quality and breath-hold technique is mandatory
4.2	Intravenous contrast media	- not required
4.3	Problems and pitfalls	- motion artefact due to dyspnoea - atelectasis may obscure pathology
4.4	Modification to technique	- prone position may be used to elucidate dependent changes, especially small areas of atelectasis - examination in suspended expiration to detect air trapping - sections with smaller inter-slice distance for evaluation of very small areas of disease - sections with a cranio-caudal -25 to -30° gantry tilt for detection of bronchiectasies

Preparatory steps:

- Indications: inflammatory lesions, abscess, suspected or known structural alteration or space occupying lesions of the abdomen and retroperitoneum, lesions of major vessels such as aneurysms and traumatic lesions, and as a guide to biopsy

- Advisable preliminary investigations: ultrasonography and/or radiography of the abdomen. MRI may be an alternative examination with regard to the retroperitoneal space

- Patient preparation: information about the procedure; exclude high density contrast media from previous investigations; oral application of contrast media for the intestine; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal from lower chest to pelvis

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of

1.1.1 Diaphragm
1.1.2 Entire liver and spleen
1.1.3 Retroperitoneal parenchymal organs (pancreas, kidneys)
1.1.4 Abdominal aorta and the proximal part of the common iliac arteries
1.1.5 Abdominal wall including all herniations
1.1.6 Vessels after intravenous contrast media

1.2 Critical reproduction

1.2.1 Visually sharp reproduction of the liver parenchyma and intrahepatic vessels
1.2.2 Visually sharp reproduction of the splenic parenchyma
1.2.3 Visually sharp reproduction of the intestine
1.2.4 Visually sharp reproduction of the perivascular retroperitoneal space
1.2.5 Visually sharp reproduction of the pancreatic contours
1.2.6 Visually sharp reproduction of the duodenum
1.2.7 Visually sharp reproduction of the kidneys and proximal ureters
1.2.8 Visually sharp reproduction of the aorta
1.2.9 Visually sharp reproduction of the aortic bifurcation and common iliac arteries
1.2.10 Reproduction of lymph nodes smaller than 15 mm in diameter
1.2.11 Reproduction of branches of the abdominal aorta
1.2.12 Visually sharp reproduction of the vena cava
1.2.13 Reproduction of tributaries to the vena cava in particular the renal veins

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1 $CTDI_W$: routine abdomen: 35 mGy

2.2 DLP : routine abdomen: 780 mGy cm

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1 Patient position : supine with arms at chest or head level

3.2 Volume of investigation : from dome of the liver to the aortic bifurcation

3.3	Nominal slice thickness	:	7-10 mm; 4-5 mm for dedicated indications only (suspected small lesions), serial or preferably helical
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0; in screening investigations, eg. for traumatic lesions $\leq$ 10 mm or a pitch up to 1.2 - 2.0
3.5	FOV	:	adjusted to the largest abdominal diameter
3.6	Gantry tilt	:	none
3.7	X-ray tube voltage (Kv)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	standard or soft tissue
3.10	Window width	:	150-600 HU 2000-3000 HU (bone, if required)
3.11	Window level	:	30-60 HU (enhanced examination) 0-30 HU (unenhanced examination) 400-600 HU (bone, if required)
3.12	Protective shielding	:	lead-purse for the male gonads if the edge of the volume of investigation is less than 10-15 cm away

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates the image quality. This is prevented by a standard breath-hold technique; alternatively if this is not possible scan during quiet respiration
4.2	Intravenous contrast media	-	useful for differentiating vessels and organ tissues from adjacent structures and to detect parenchymal lesions in solid organs
4.3	Problems and pitfalls	-	non-contrasted parts of the intestine may mimic tumours
		-	the delineation of organs and structures may be poor in cachectic patients with reduced intra-abdominal and retroperitoneal fat
4.4	Modification to technique	-	helical CT which is beneficial for elimination of motion artefact can be used for demonstrating vascular pathologies (CT angiography)
		-	may be combined with examination of the pelvis

LIVER AND SPLEEN

Preparatory steps:

- Indications: suspected or known focal or diffuse disease of the liver, biliary tree, gallbladder, spleen or adjacent structures

- Advisable preliminary investigations: ultrasonography; MRI may be an alternative examination without exposure to ionising radiation

- Patient preparation: information about the procedure; exclude high density contrast media form previous investigations; oral contrast media for bowel and stomach demarcation; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal from lower chest to pelvis

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 **Visualization of**
1.1.1 Entire liver
1.1.2 Entire spleen
1.1.3 Vessels after intravenous contrast media

1.2 Critical reproduction
1.2.1 Visually sharp reproduction of the liver parenchyma and intrahepatic portal veins
1.2.2 Visually sharp reproduction of the liver veins
1.2.3 Visually sharp reproduction of the structures of the liver hilus
1.2.4 Visually sharp reproduction of the common hepatic duct
1.2.5 Reproduction of the ductus choledochus (common bile duct) in the pancreatic parenchyma
1.2.6 Reproduction of the gallbladder wall
1.2.7 Visually sharp reproduction of the splenic parenchyma
1.2.8 Visually sharp reproduction of the splenic artery
1.2.9 Visually sharp reproduction of the extrahepatic portal vein system including v. lienalis and v. mesenterica sup.
1.2.10 Visually sharp reproduction of the aorta and inferior vena cava
1.2.11 Visually sharp reproduction of the origin of the coeliac trunk
1.2.12 Visually sharp reproduction of the mesenteric artery

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	35 mGy (pilot study (17))
2.2	DLP	:	900 mGy cm (pilot study)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine with arms at chest or head level
3.2	Volume of investigation	:	from above diaphragm to 1 cm below the caudal end of the liver and spleen
3.3	Nominal slice thickness	:	7-10 mm; 4-5 mm if small lesions are

			suspected, serial or preferably helical
3.4	Inter-slice distance	:	contiguous or a pitch = 1.0; ≤10 mm or a pitch up to 1.2 - 2.0 in screening investigations
3.5	FOV	:	adjusted to the largest diameter of the abdomen within the volume under investigation
3.6	Gantry tilt	:	none
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue/standard
3.10	Window width	:	150-300 HU
3.11	Window level	:	40-80 HU (enhanced examination) 0-30 HU (unenhanced examination)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	- movement artefact deteriorates the image quality. This is prevented by standard breath-hold technique; alternatively if this is not possible scan during quiet respiration - cardiac motion may cause artefacts in left liver lobe
4.2	Intravenous contrast media	- useful to delineate organ tissue and vessels and detect focal lesions in solid organs - multiphased section examination may be indicated
4.3	Problems and pitfalls	- inconsistent breath holding between slices may obscure subtle pathology in serial CT - differentiation of small hepatic or splenic cysts from tumours can be difficult - inhomogeneous attenuation during initial contrast enhancement may mimic focal hepatic or splenic disease - non-calcified bile stones may not be identifiable
4.4	Modification to technique	- in case of suspected haemangioma, serial CT of the pathology several minutes after injection of contrast media - additional thinner slices may be obtained to delineate subtle alterations

KIDNEYS

Preparatory steps:

- Indications: suspected or known focal or diffuse structural disease of the kidneys, and traumatic lesions

- Advisable preliminary investigations: ultrasonography; blood-creatinine (especially prior to administration of contrast media). MRI may be an alternative examination without exposure to ionising radiation

- Patient preparation: information about the procedure; exclude high density contrast media from previous investigations; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal from liver dome to upper pelvis

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 **Visualization of**
1.1.1 Both kidneys
1.1.2 Proximal part of the ureters
1.1.3 Vessels after intravenous contrast media

1.2 Critical reproduction
1.2.1 Visually sharp reproduction of the renal parenchyma
1.2.2 Visually sharp reproduction of the renal pelvis and calices/
1.2.3 Visually sharp reproduction of the proximal part of the ureters
1.2.4 Visually sharp reproduction of the perirenal spaces
1.2.5 Visually sharp reproduction of the aorta and vena cava
1.2.6 Visually sharp reproduction of the renal arteries
1.2.7 Visually sharp reproduction of the renal veins

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine abdomen: 35 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine abdomen: 800 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine with arms at chest or head level
3.2	Volume of investigation	:	1 cm above the most cranial pole of the kidneys to 1 cm below the most caudal pole; depending on the findings (eg. tumour) extension of the volume may be needed
3.3	Nominal slice thickness	:	4-5 mm for unknown or small pathologies; 7-10 mm for follow up of larger lesions
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0

3.5	FOV	:	adjusted to the largest diameter of the abdomen within the volume under investigation; secondary magnification by reducing the FOV may be necessary for evaluation of subtle pathology
3.6	Gantry tilt	:	none
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue/standard
3.10	Window width	:	200-400 HU
3.11	Window level	:	30-150 HU (enhanced examination) 0-30 HU (unenhanced examination)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates the image quality. This is prevented by a standard breath-hold technique; alternatively if this is not possible scan during quiet respiration
4.2	Intravenous contrast media	-	combination of native and contrast enhanced studies are necessary in most patients to characterise lesions or distinguish them from vessels
		-	multiphased section examination may be indicated. An optimal injection protocol is then important
4.3	Problems and pitfalls	-	inconsistent breath holding between slices may obscure subtle pathology in serial CT
		-	differentiation of small cysts from tumours may be difficult
		-	non-calcified stones may not be identifiable
4.4	Modification to technique	-	additional thinner slices may be obtained to delineate minor alterations

PANCREAS

Preparatory steps:

- Indications: suspected or known focal or diffuse disease of the pancreas or peripancreatic structures

- Advisable preliminary investigations: ultrasonography; laboratory investigations (amylase, lipase). MRI may be an alternative examination without exposure to inonising radiation

- Patient preparation: information about the procedure; exclude high density contrast media from previous investigations; oral contrast media directly prior to the examination (in right lateral position) to demarcate the duodenum; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal from lower chest to middle abdomen

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of

1.1.1 Entire pancreas (head, body, tail, uncinate process)
1.1.2 Entire diseased peripancreatic tissue
1.1.3 Adjacent parts of liver, spleen, bowels and stomach
1.1.4 Vessels after intravenous contrast media

1.2 Critical reproduction

1.2.1 Visually sharp reproduction of the pancreatic contours
1.2.2 Visually sharp reproduction of the pancreatic parenchyma
1.2.3 Reproduction of the pancreatic duct
1.2.4 Visually sharp reproduction of the common bile duct within the pancreatic head
1.2.5 Visually sharp reproduction of the mesenteric artery and vein
1.2.6 Visually sharp reproduction of the splenic artery and vein
1.2.7 Visually sharp reproduction of the portal vein
1.2.8 Visually sharp reproduction of the coeliac trunk
1.2.9 Visually sharp reproduction of diaphragmatic crura
1.2.10 Visually sharp reproduction of the aorta
1.2.11 Visually sharp reproduction of the vena cava
1.2.12 Visually sharp reproduction of the renal vessels
1.2.13 Visually sharp reproduction of the duodenum

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine abdomen: 35 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine abdomen: 800 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine with arms at chest or head level
3.2	Volume of investigation	:	1-2 cm above the pancreatic tail to 1-2 cm below the uncinate process; larger volume may

			be needed to include all peripancreatic lesions such as pseudocysts or exudates
3.3	Nominal slice thickness	:	3-5 mm; 7-10 mm in known larger lesions, serial or preferably helical
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0; 5-10 mm or a pitch up to 1.2-2.0 for exudates caudal to the pancreas
3.5	FOV	:	adjusted to the largest diameter of the abdomen within the volume under investigation; secondary magnification by reducing the FOV may be necessary for evaluation of subtle pathology
3.6	Gantry tilt	:	none
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue
3.10	Window width	:	150 - 400 HU
3.11	Window level	:	30 - 50 HU (enhanced examination) 0 - 30 HU (unenhanced examination)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates the image quality. This is prevented by a standard breath-hold technique; alternatively if this is not possible scan during quiet respiration
4.2	Intravenous contrast media	-	useful for delineation of tumorous or inflammatory disease
		-	scanning early after injection of intravenous contrast media is useful for detection of intrapancreatic tumours
4.3	Problems and pitfalls	-	inconsistent breath holding between slices may obscure subtle pathology in serial CT
		-	insufficient differentiation of pancreatic head and duodenum due to lack of oral contrast media in duodenum
		-	insufficient pancreatic delineation in patients with reduced retroperitoneal fatty tissue
4.4	Modification to technique	-	bowel motion may require spasmolytic therapy
		-	the examination may be extended to include the liver with contrast in the portovenous phase

in the case of tumour suspicion
- intra-arterial contrast media may be used for detection of endocrine pancreatic tumours

ADRENAL GLANDS

Preparatory steps:

- Indications: suspected or known focal or diffuse structural disease of the adrenal glands

- Advisable preliminary investigations: ultrasonography; scintigraphy; laboratory investigations. MRI may be an alternative examination without exposure to ionising radiation

- Patient preparation: information about the procedure; exclude high density contrast media from previous investigations; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal from lower chest to middle abdomen

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of

1.1.1 Both adrenal glands
1.1.2 Upper perirenal spaces
1.1.3 Vessels after intravenous contrast media

1.2 Critical reproduction

1.2.1 Visually sharp reproduction of the right adrenal body
1.2.2 Visually sharp reproduction of the right adrenal crura
1.2.3 Visually sharp differentiation of the right adrenal gland from adjacent structures
1.2.4 Visually sharp reproduction of the left adrenal body
1.2.5 Visually sharp reproduction of the left adrenal crura
1.2.6 Visually sharp differentiation of the left adrenal gland from adjacent structures
1.2.7 Visually sharp reproduction of the diaphragmatic crura
1.2.8 Visually sharp reproduction of the aorta
1.2.9 Visually sharp reproduction of the vena cava

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available (for information: routine abdomen: 35 mGy)
2.2	DLP	:	no specific value as yet available (for information: routine abdomen: 800 mGy cm)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine with arms at chest or head level
3.2	Volume of investigation	:	1-2 cm above to 1-2 cm below the adrenal glands
3.3	Nominal slice thickness	:	2-5 mm, serial or preferably helical; can be larger if pathology is already known.
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0; in the case of minor

			pathology, overlapping slices by serial CT
3.5	FOV	:	adjusted to the largest diameter of the abdomen within the volume under investigation; secondary magnification by reducing the FOV may be necessary for evaluation of subtle pathology
3.6	Gantry tilt	:	none
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue
3.10	Window width	:	150 - 400 HU
3.11	Window level	:	30 - 50 HU (enhanced examination) 0 - 30 HU (unenhanced examination)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates the image quality. This is prevented by a standard breath-hold technique; alternatively if this is not possible scan during quiet respiration
4.2	Intravenous contrast media	-	useful to improve delineation of the adrenals from adjacent organs or structures, and for characterization of tumours
4.3	Problems and pitfalls	-	inconsistent breath holding between slices may obscure subtle pathology in serial CT
		-	insufficient adrenal delineation in patients with reduced retroperitoneal fatty tissue
4.4	Modification to technique	-	administration of oral contrast media to improved delineation from adjacent organs or structures

PELVIS, GENERAL

Preparatory steps:

- Indications: disorders of the prostate, uterus or female gonads and suspected or known focal or diffuse structural disease of the pelvis eg. lymphomas

- Advisable preliminary investigations: ultrasonography and MRI are alternative examinations without exposure to ionising radiation; endoscopy (for intraluminal pathology)

- Patient preparation: information about the procedure; exclude high density contrast media from previous investigations; administration of oral or rectal contrast media for bowel demarcation; vaginal contrast tampon in gynaecological indications. Urinary bladder should not be empty; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal from iliac crest to proximal femur

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of

1.1.1 Entire iliac bones
1.1.2 Entire ischial bones
1.1.3 Entire pubic symphysis
1.1.4 Entire urinary bladder
1.1.5 All peripelvic muscles
1.1.6 Vessels after intravenous contrast media

1.2 Critical reproduction

1.2.1 Visually sharp reproduction of the bladder wall
1.2.2 Reproduction of the distal portion of the ureters
1.2.3 Visually sharp reproduction of the rectum
1.2.4 Visually sharp differentiation of the perirectal space
1.2.5 Visually sharp reproduction of the uterus
1.2.6 Visually sharp reproduction of the parametrical tissues or seminal vesicles
1.2.7 Visually sharp reproduction of the prostata

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	routine pelvis: 35 mGy
2.2	DLP	:	routine pelvis: 570 mGy cm

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine with arms at chest or head level
3.2	Volume of investigation	:	from iliac crest to pelvic floor
3.3	Nominal slice thickness	:	7-10 mm; 4-5 mm if small lesions are suspected, serial or preferably helical CT
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0; 4-5 mm or a pitch up to 1.2-1.5 may be used in screening

			examinations
3.5	FOV	:	adjusted to the maximum diameter of the pelvis
3.6	Gantry tilt	:	none
3.7	X-ray tube voltage (kV)	:	standard
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue/standard or high resolution if bone evaluation is required
3.10	Window width	:	200 - 600 HU (soft tissues) 2000 - 3000 HU (bones)
3.11	Window level	:	30 - 60 HU (enhanced examination) 0 - 30 HU (unenhanced examination) 400 - 600 HU (bones)
3.12	Protective shielding	:	lead-purse for the male gonads

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates the image quality
4.2	Intravenous contrast media	-	useful for delineation of neoplastic or inflammatory diseases and distinguishing lesions from vessels
4.3	Problems and pitfalls	-	delineation of organs and structures may be difficult in cachectic patients with reduced intra-abdominal and retroperitoneal fatty tissue
		-	folds of the bowel wall or stool may mimic tumour
		-	empty urinary bladder
		-	contrast media "jets" from the ureters into the urinary bladder
4.4	Modification to technique	-	additional thinner slices to delineate small alterations
		-	additional enteral contrast media may be needed to visualise the bowel
		-	additional i.v. contrast media with regard to the urinary bladder
		-	filling of the urinary bladder by oral water intake

OSSEOUS PELVIS

Preparatory steps:

- Indications: evaluation or verification of pelvic ring and acetabular fractures, hip dislocation, bone tumours, degenerative, infectious, arthritic and osteonecrotic changes

- Advisable preliminary investigations: always conventional radiography; MRI or ultrasonography may be alternative examinations without exposure to ionising radiation in non-traumatic disorders

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal from iliac crest to ischial tuberosity

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of
1.1.1 Whole pelvic ring
1.1.2 Hip(s) including the trochanter region
1.1.3 Sacroiliac joints
1.1.4 Pubic symphysis

1.2 Critical reproduction
1.2.1 Visually sharp reproduction of the pelvic bones
1.2.2 Visually sharp reproduction of the hip joint(s)
1.2.3 Visually sharp reproduction of the sacroiliac joints
1.2.4 Visually sharp reproduction of the pubic symphysis
1.2.5 Visually sharp reproduction of the pelvic musculature

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	25 mGy (pilot study (17))
2.2	DLP	:	520 mGy cm (pilot study)

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine with arms at chest or head level
3.2	Volume of investigation	:	tumour/fracture: from 1 cm above to 1 cm below the diseased area; joint disorders: 1 cm above to 1 cm below the joint region
3.3	Nominal slice thickness	:	3-5 mm in the hip region; 3-10 mm outside the hip, serial or preferably helical
3.4	Inter-slice distance/pitch	:	contiguous or pitch = 1.0 in the hip region, <5 mm or a pitch up to 1.2-1.5 outside the hip region
3.5	FOV	:	pelvis, hip or sacroiliac joint dimension (usually 15-40 cm)

3.6	Gantry tilt	:	usually none, but cranial tilting should be used for examination of the sacroiliac joints to reduce radiation to the female gonads
3.7	X-ray tube voltage (kV)	:	standard or high kV in large persons to avoid noise
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue/standard or high resolution
3.10	Window width	:	1000-1500 HU (joints/bones) 200-600 HU (soft tissue)
3.11	Window level	:	150-200 HU (joints/bones) 30-50 HU (soft tissue)
3.12	Protective shielding	:	lead-purse for the male gonads

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates image quality and the value of reconstructions
4.2	Intravenous contrast media	-	useful for delineating malignant and inflammatory lesions extending into the soft tissue, and for detecting traumatic lesion of pelvic organs
4.3	Problems and pitfalls	-	artefact due to metallic objects such as prothesis
4.4	Modification to technique	-	intracavitary contrast media to delineate traumatic lesion of pelvic organs

OSSEOUS SHOULDER

Preparatory steps:

- Indications: evaluation or verification of fracture/dislocation, bone tumours, degenerative, infectious, arthritic and osteonecrotic changes

- Advisable preliminary investigations: always conventional radiography; MRI or ultrasonography may be alternative examinations without exposure to ionising radiation in non-traumatic disorders

- Patient preparation: information about the procedure; restraint from food, but not fluid, is recommended, if intravenous contrast media are to be given

- Scan projection radiograph: frontal from top of acromion extending 12-25 cm caudally, depending on suspected pathology

1. DIAGNOSTIC REQUIREMENTS

Image criteria:

1.1 Visualization of
1.1.1 Shoulder joint
1.1.2 Whole scapula
1.1.3 Proximal 8 cm or more of the humerus

1.2 Critical reproduction
1.2.1 Visually sharp reproduction of the bones (humerus, scapula, lateral end of the clavicle)
1.2.2 Visually sharp reproduction of the shoulder joint
1.2.3 Visually sharp reproduction of the musculature and other soft tissue structures

2. CRITERIA FOR RADIATION DOSE TO THE PATIENT

2.1	$CTDI_W$	:	no specific value as yet available
2.2	DLP	:	no specific value as yet available

3. EXAMPLES OF GOOD IMAGING TECHNIQUE

3.1	Patient position	:	supine; if necessary slightly oblique; diseased shoulder as near gantry centre as possible with diseased arm along the body, the other arm above the head
3.2	Volume of investigation	:	humeral and scapular fracture/tumour: the fracture/tumour area; joint disorders: top of acromion to 1 cm below the glenohumeral joint
3.3	Nominal slice thickness	:	3-5 mm, serial or preferably helical
3.4	Inter-slice distance/pitch	:	contiguous or a pitch = 1.0 in the joint region; 2-5 mm or a pitch up to 1.2-1.5 outside the joint region
3.5	FOV	:	shoulder dimension (usually 15-20 cm)
3.6	Gantry tilt	:	none

3.7	X-ray tube voltage (kV)	:	standard or high kV in large persons to avoid noise
3.8	Tube current and exposure time product (mAs)	:	should be as low as consistent with required image quality
3.9	Reconstruction algorithm	:	soft tissue/standard or high resolution
3.10	Window width	:	1000-1500 HU (joints/bones) 200-600 HU (soft tissue)
3.11	Window level	:	150-200 HU (joints/bones) 30-50 HU (soft tissue)

4. CLINICAL CONDITIONS WITH IMPACT ON GOOD IMAGING PERFORMANCE

4.1	Motion	-	movement artefact deteriorates image quality and the value of reconstructions (can sometimes be prevented by suspended inspiration)
4.2	Intravenous contrast media	-	useful for delineating malignant and inflammatory lesions extending into the soft tissue
4.3	Problems and pitfalls	-	immobility preventing correct positioning and causing artefact
4.4	Modification to technique	-	intra-articular contrast media for outlining intra-articular structures

LIST OF REFERENCES FOR CHAPTER 1

1. ICRP Publication 60, 1990 Recommendations of the International Commission on Radiological Protection, Annals of the ICRP Vol. **21** Nos. 1-3 (Pergamon Press, Oxford) (1991)

2. ICRP Publication 34, Protection of the Patient in Diagnostic Radiology, Annals of the ICRP Vol. **9** Nos. 2-3 (Pergamon Press, Oxford) (1982)

3. ICRP Publication 73, Radiological Protection and Safety in Medicine, Annals of the ICRP Vol. **26** No. 2 (Pergamon Press, Oxford) (1996)

4. Council Directive 97/43/EURATOM of 30 June 1997 on health protection of individuals against the dangers of ionizing radiation in relation to medical exposure. O.J. No. L 180, p. 22, 9.7.1997. (Repealing Directive 84/466/EURATOM, O.J. L 265, p.1, 5.10.1984)

5. European Guidelines on Quality Criteria for Diagnostic Radiographic Images, Report EUR 16260 (1996)

6. European Guidelines on Quality Criteria for Diagnostic Radiographic Images in Paediatrics, Report EUR 16261 (1996)

7. Hidajat N, Schröder RJ, Vogl T, Schedel H and Helix R. Effektivität der Bleiabdeckung zur Dosisreduktion beim Patienten in der Computertomographie. Fortschritte Röntgenstrahlen, **165**, 462 - 465 (1996)

8. Beaconsfield T, Nicholson R, Tornton A and Al-Kutoubi A. Would thyroid and breast shielding be beneficial in CT of the head? European Radiology, **8,** 664 - 667 (1998)

9. Shrimpton PC, Jones DG, Hillier MC, Wall BF, Le Heron JC and Faulkner K. Survey of CT practice in the UK. Part 2: Dosimetric aspects. Chilton, NRPB-R249 (London, TSO) (1991)

10. Brink JA, McFarland EG and Heiken JP. Helical/spiral computed body tomography. Clinical Radiology, **52** (7), 489-503 (1997)

11. Costello P, Dupuy DE, Ecker CP and Tello R. Spiral CT of the thorax with reduced volume of contrast material: a comparative study. Radiology, **183** (3), 663-666 (1992)

12. Jurik AG and Albrechtsen J. Spiral-CT with three-dimensional and multiplanar reconstruction in the diagnosis of anterior chest wall disorders. Acta Radiologica, **35**, 468-472 (1994)

13. Kalender WA. Technical foundations of spiral CT. Seminars in Ultrasound, CT and MRI, **15** (2), 81 - 89 (1994)

14. Verdun FR, Meuli RA, Bochud FO, Imsand C, Raimondi S, Schnyder P and Vally J-F. Image quality and dose in spiral computed tomography. European Radiology, **6**, 485-488 (1996)

15. Reynolds MD, Heuscher DJ and Vembar M. Evaluation of spiral CT on a fourth-generation system. European Radiology, **5**, 102-109 (1995)

16. International Electrotechnical Commission: Evaluation and routine testing in medical imaging departments. Part 2 - 6: Constancy tests - x-ray equipment for computed tomography, 1994: IEC 1223-2-6 (Geneva, IEC)

17. Jurik AG, Petersen J, Bongartz, Golding SJ, Leonardi M, van Meerten PvE, Geleijns J, Jessen KA, Panzer W, Shrimpton P, Tosi G. Clinical use of image quality criteria in computed tomography related to radiation dose. A pilot study. European Radiology (to be submitted)

Chapter 1
APPENDIX I

GUIDELINES ON RADIATION DOSE TO THE PATIENT

OBJECTIVE

The conditions of exposure during CT examinations are quite different from those in conventional x-ray procedures and specific techniques are necessary in order to allow detailed assessment of patient dose from CT. National surveys of CT practice using such methods of dosimetry have established the increasing importance of CT as a significant source of medical x-rays for populations in developed countries (1). Evidence from dose surveys has also indicated potential scope for improvement in the optimisation of protection for patients undergoing CT and the need for more widespread assessment of typical levels of patient dose as part of routine quality assurance (2,3). Inherent differences in the design of CT equipment lead to variations between scanner models by up to a factor of three in the calculated values of *effective dose* for standard examinations under conditions of similar image quality (4). However, larger variations in dose are apparent in clinical practice, with the minimum and maximum values of typical dose for a given type of procedure varying by factors, for example, of 10-40 in the UK (4) and 8-20 in Norway (5); this is largely as a result of differences in the local scanning technique typically employed for a particular type of examination, as determined by the number and thickness of slices imaged, the couch increment between slices, the use of contrast medium for additional scans and the exposure settings selected.

The Examples of Good Imaging Technique given in the Lists of Quality Criteria are intended to help avoid unnecessary exposures in CT. The Criteria for Radiation Dose to the Patient indicate diagnostic reference dose values for general types of examination as a practical means of promoting strategies for optimisation of patient protection. The purpose of a reference dose quantity for a diagnostic medical exposure is to provide quantification of performance and allow comparison of examination techniques at different hospitals. **Diagnostic reference dose values should not be applied locally on an individual patient basis, but rather to the mean doses observed for representative groups of patients.** Reference dose values are intended to act as thresholds to trigger internal investigations by departments where typical practice is likely to be well away from the optimum and where improvements in dose-reduction are probably most urgently required. **Typical levels of dose in excess of a reference dose value should either be thoroughly justified or reduced.** In general, patient doses should always be reduced to the lowest levels that are reasonably practicable and consistent with the clinical purpose of the examination.

The derivation of the diagnostic reference dose values is described in Chapter 2. Reference dose quantities and methods for their assessment are discussed below.

COMPUTED TOMOGRAPHY DOSE INDEX (CTDI)

The principal dosimetric quantity used in CT is the *computed tomography dose index (CTDI)*. This is defined (6) as the integral along a line parallel to the axis of rotation (z) of the dose profile (D(z)) for a single slice, divided by the nominal slice thickness T:

$$CTDI = \frac{1}{T}\int_{-\infty}^{+\infty} D(z)dz \quad \text{(mGy)} \quad (1)$$

In practice, a convenient assessment of CTDI can be made using a pencil ionisation chamber with an active length of 100 mm so as to provide a measurement of $CTDI_{100}$ expressed in terms of absorbed dose to air (mGy). Such measurements may be carried out free-in-air on or parallel with the axis of rotation of the scanner ($CTDI_{100,\,air}$), or at the centre ($CTDI_{100,\,c}$) and 10 mm below the surface ($CTDI_{100,\,p}$) of standard CT dosimetry phantoms. The subscript `n' ($_nCTDI$) is used to denote when these measurements have been normalised to unit radiographic exposure (mAs). Further discussion of the quantity CTDI is given in Chapter 2.

Such measurements of CTDI in the standard head or body CT dosimetry phantom may be used to provide an indication of the average dose over a single slice for each setting of nominal slice thickness. On the assumption that dose in a particular phantom decreases linearly with radial position from the surface to the centre, then the normalised average dose to the slice (7) is approximated by the (normalised) weighted CTDI ($CTDI_w$):

$$ {}_nCTDI_w = \frac{1}{C}\,(1/3\,CTDI_{100,c} + 2/3\,CTDI_{100,p}) \qquad (mGy(mAs)^{-1}) \quad (2) $$

where C is the radiographic exposure (mAs) and $CTDI_{100,p}$ represents an average of measurements at four different locations around the periphery of the phantom. Values of ${}_nCTDI_w$ can vary with nominal slice thickness, particularly for the narrowest settings.

REFERENCE DOSE QUANTITIES

Two reference dose quantities are proposed for CT in order to promote the use of good technique:

(a) Weighted CTDI in the standard head or body CT dosimetry phantom for a single slice in serial scanning or per rotation in helical scanning:

$$ CTDI_w = {}_nCTDI_w \cdot C \qquad (mGy) \quad (3) $$

where ${}_nCTDI_w$ is the normalised weighted CTDI in the head or body phantom for the settings of nominal slice thickness and applied potential used for an examination (Equation 2) and C is the radiographic exposure (mAs) for a single slice in serial scanning or per rotation in helical scanning.

Monitoring of $CTDI_w$ for the head or body CT dosimetry phantom, as appropriate to the type of examination, provides control on the selection of exposure settings, such as mAs.

(b) Dose-length product for a complete examination:

$$ DLP = \sum_i {}_nCTDI_w \cdot T \cdot N \cdot C \qquad (mGy\ cm) \quad (4) $$

where i represents each serial scan sequence forming part of an examination and N is the number of slices, each of thickness T (cm) and radiographic exposure C (mAs), in a particular sequence. Any variations in applied potential setting during the examination will require corresponding changes in the value of ${}_nCTDI_w$ used.

In the case of helical (spiral) scanning:

$$ DLP = \sum_i {}_nCTDI_w \cdot T \cdot A \cdot t \qquad (mGy\ cm) \quad (5) $$

where, for each of i helical sequences forming part of an examination, T is the nominal irradiated slice thickness (cm), A is the tube current (mA) and t is the total acquisition time (s) for the sequence. ${}_nCTDI_w$ is determined for a single slice as in serial scanning.

Monitoring of DLP provides control on the volume of irradiation and overall exposure for an examination.

Procedures for estimating $CTDI_w$ and DLP are given below.

METHODS OF DOSE ASSESSMENT TO CHECK COMPLIANCE WITH THE CRITERIA

Comparison of performance against the criteria for each particular type of examination requires assessment of the values of the reference dose quantities associated with the parameters of technique typically used when scanning a standard-sized adult patient. **In the absence of a well-defined scanning protocol, typical dosimetric practice should be determined on the basis of the mean results derived for a sample of at least 10 patients for each procedure.**

$CTDI_w$ may be assessed directly from Equations (2) and (3) using the results of measurements of $CTDI_{100,\,p\ or\ c}$ for the head or body CT dosimetry phantom carried out during routine performance

testing. Such measurements may be accomplished using thermoluminescent dosemeters (TLDs) or more conveniently using an appropriately calibrated 100 mm long pencil-shaped ionisation chamber (8). It has been recommended by the International Electrotechnical Commission that values of $CTDI_w$ should be displayed on the operator's console of the CT scanner, reflecting the conditions of operation selected, although an appropriate correction should be included if the nominal slice thickness is not equal to the couch increment per tube rotation (9). Typical values of ${}_nCTDI_w$ for a wide range of scanner models have been collated into a reference database on CT dosimetry that has been published on the Internet (10). Some standard dose data for a selection of scanners is given, for illustrative purposes, in Appendix I to Chapter 2.

Estimates of $CTDI_w$ may also be made using the typical dose data commonly provided by manufacturers in fulfilment of the requirements of the Food and Drug Administration (FDA) in the USA. Accordingly, manufacturers of CT scanners are obliged to report values of CTDI measurements in the standard head and body CT dosimetry phantoms using a specific protocol (11) for which there are important differences from the approach advocated in this report; such values of $CTDI_{FDA}$ refer to an integration length equivalent to 14 nominal slice thicknesses (rather than 100 mm) and are expressed in terms of absorbed dose to PMMA (rather than air). Similar measurements have previously been recommended by the International Electrotechnical Commission (IEC) as part of constancy testing in CT (12). However, values of $CTDI_{FDA}$ determined in the phantoms will be only slightly less than $CTDI_{100}$ for the largest settings of slice thickness, but more significantly so for smaller slice thicknesses. Table 1 gives broad factors (13) to allow the estimation of $CTDI_w$ from such manufacturers data ($CTDI_{FDA}$).

As a practical alternative, estimates of $CTDI_w$ for the head or body CT dosimetry phantom may be derived from simpler measurements of CTDI made free-in-air ($CTDI_{air}$) under similar conditions of exposure (H = head, B = body):

$$CTDI_w = CTDI_{air} \cdot P_{H\ or\ B} \qquad (mGy\ cm) \quad (6)$$

where the factor $P_{H\ or\ B}$ is given by:

$$P_H = \frac{({}_nCTDI_w)_H}{{}_nCTDI_{air}} \qquad (7)$$

and

$$P_B = \frac{({}_nCTDI_w)_B}{{}_nCTDI_{air}} \qquad (8)$$

Measurements of $CTDI_{air}$ are easily accomplished with either the 100 mm pencil-shaped ionisation chamber or a shorter length of TLDs since the tails on the dose profiles in air are less significant than in a phantom in view of the lower amount of *scattered radiation*. Some typical values of the factor P for selected scanner models are given in Appendix I to Chapter 2. Further data for a wider range of models are available in the reference database on CT dosimetry (10).

Subsequent estimates of DLP for an examination may be derived using Equations (4) and (5), with knowledge of appropriate values of ${}_nCTDI_w$ for the scanner and details of the particular scanning protocol used. In the case of examinations involving separate scanning sequences in which different technique parameters are applied (such as slice thickness or radiographic exposure, for example), the total DLP should be determined for the entire procedure as the sum of the contributions from each serial or helical sequence.

ASSESSMENT OF EFFECTIVE DOSE

In addition to comparison of performance against reference dose values, there is sometimes a need to assess effective dose (14) for CT procedures so as, for example, to allow comparison with other types of radiological examination. The effective dose for a particular scanning protocol may be estimated from a measurement of $CTDI_{air}$ utilising scanner-specific normalised organ

dose data determined for a mathematical anthropomorphic phantom using *Monte Carlo techniques* (15,16). For types of scanner not included amongst these calculations, appropriate data sets may be selected from those available on the basis of similarity of values of P (Equations (7) and (8)) (17,18).

Alternatively, broad estimates of effective dose (E) may be derived from values of DLP for an examination using appropriately normalised coefficients:

$$E = E_{DLP} \cdot DLP \quad (mSv) \qquad (9)$$

where DLP (mGy cm) is the dose-length product as defined in Equations (4) or (5) and E_{DLP} is the region-specific normalised effective dose (mSv mGy^{-1} cm^{-1}).

General values of E_{DLP} appropriate to different anatomical regions of the patient (head, neck, chest, abdomen or pelvis) are given in Table 2.

Such an estimate of effective dose may also be derived from a measurement of $CTDI_{air}$ on the basis of Equation (6) and Equations (4) or (5) to determine DLP.

LIST OF REFERENCES FOR APPENDIX 1 TO CHAPTER 1

1. Shrimpton PC and Wall BF. The increasing importance of x-ray computed tomography as a source of medical exposure. Radiation Protection Dosimetry, **57** (1-4), 413-415 (1995)

2. NRPB. Protection of the patient in x-ray computed tomography. Documents of the NRPB, **3**, No. 4, (1992)

3. Shrimpton PC, Jessen KA, Geleijns J, Panzer W and Tosi G. Reference doses in computed tomography. Radiation Protection Dosimetry, **80** (1-3), 55-59 (1998)

4. Shrimpton PC, Jones DG, Hillier MC, Wall BF, Le Heron JC and Faulkner K. Survey of CT practice in the UK. Part 2: Dosimetric aspects. Chilton, NRPB-R249 (London, TSO) (1991)

5. Olerud HM. Analysis of factors influencing patient doses from CT in Norway. Radiation Protection Dosimetry, **71** (2), 123-133 (1997)

6. Shope TB, Gagne RM and Johnson GC. A method for describing the doses delivered by transmission x-ray computed tomography. Medical Physics, **8** (4), 488-495 (1981)

7. Leitz W, Axelsson B and Szendrö G. Computed tomography dose assessment - a practical approach. Radiation Protection Dosimetry, **57** (1-4), 377-380 (1995)

8. Suzuki A and Suzuki MN. Use of a pencil-shaped ionization chamber for measurement of exposure resulting from a computed tomography scan. Medical Physics, **5** (6), 536-539 (1978)

9. International standard of IEC 60601-2-44: Medical electrical equipment - Part 2-44: Particular requirements for the safety of x-ray equipment for computed tomography (1999)

10. Internet address of the Reference Database on CT Dosimetry: http://www.efomp.org

11. Department of Health and Human Services, Food and Drug Administration. 21 CFR

Part 1020: Diagnostic x-ray systems and their major components; amendments to performance standard; Final rule. Federal Register, **49**, 171 (1984)

12. International Electrotechnical Commission. IEC 1223-2-6: Evaluation and routine testing in medical imaging departments. Part 2-6: Constancy tests - X-ray equipment for computed tomography. (Geneva, IEC) (1994)

13. Edyvean S, Lewis MA, Britten AJ, Carden JF, Howard GA and Sassi SA. Type testing of CT scanners: methods and methodology for assessing imaging performance and dosimetry. MDA Evaluation Report MDA/98/25. London, Medical Devices Agency (1998)

14. ICRP Publication 60, 1990 Recommendations of the International Commission on Radiological Protection, Annals of the ICRP Vol. **21** Nos. 1-3 (Pergamon Press, Oxford) (1991)

15. Jones DG and Shrimpton PC. Normalised organ doses for x-ray computed tomography calculated using Monte Carlo techniques. Chilton, NRPB-SR250 (1993)

16. Zankl M, Panzer W and Drexler G. The calculation of dose from external photon exposures using reference human phantoms and Monte Carlo methods. Part VI: Organ doses from computed tomographic examinations. GSF-Bericht 30/91 (Neuherberg, Gesellschaft für Strahlen- und Umweltforschung) (1991)

17. Shrimpton PC. Unpublished data (1995)

18. Geleijns J. Patient dosimetry in diagnostic radiology. Thesis, Leiden University (1995)

Table 1 Broad factors to allow estimation of $CTDI_{100}$ from measurements of $CTDI_{FDA}$ in standard CT dosimetry phantoms by manufacturers

Phantom	Slice thickness (mm)	Ratio $_nCTDI_{100}$ / $_nCTDI_{FDA}$	
		Centre of phantom	1 cm depth
Head	10	1.0	1.1
	5	1.3	1.2
	3	1.6	1.3
	2	2.0	1.5
Body	10	1.0	1.1
	5	1.4	1.2
	3	1.9	1.3
	2	2.6	1.5

Table 2 Normalised values of effective dose per dose-length product (DLP) over various body regions

Region of body	Normalised effective dose, E_{DLP} (mSv mGy^{-1} cm^{-1})
Head	0.0023
Neck	0.0054
Chest	0.017
Abdomen	0.015
Pelvis	0.019

Chapter 2

SUMMARY OF RESEARCH RESULTS AND ONGOING EXPERIMENTS RELATED TO THE ESTABLISHMENT OF QUALITY CRITERIA FOR CT AND REFERENCE DOSE VALUES

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Chapter 2

ESTABLISHMENT OF QUALITY CRITERIA

INTRODUCTION

The concept of quality criteria for diagnostic x-ray examinations was introduced by the CEC as European Guidelines on 'Quality Criteria for Diagnostic Radiographic Images' (1).These provide guidance on diagnostic requirements, the radiation dose to the patient and the choice of radiographic technique. The concept was subsequently applied to paediatric radiology (2) and, in this report, is now being extended to CT. In the meantime evaluations of the application of quality criteria have been performed for conventional radiography images and CT, as summarised below.

CONVENTIONAL RADIOGRAPHY

Quality criteria for conventional diagnostic radiographic images in adult radiology have been developed over a period of about ten years during which two European-wide trials have been conducted in order to assess relevance, acceptability and ease of use for technical and clinical staff in diagnostic x-ray departments. The findings of the trials provide a supplementary scientific background to the application of such quality criteria (3,4).

The first European trial (3) was conducted in 1987/88 and involved information from 24 x-ray departments in 10 European countries. It concerned radiographic technique and compliance with the image criteria given in the preliminary Quality Criteria Working Document. The results confirmed the validity of the application of quality criteria as a tool for the optimisation of radiation protection. In particular they permitted the identification of suitable technical modalities for achieving the best possible compromise between the essential medical information in a radiographic image and the patient dose. However, the trial clearly highlighted the need for establishing quality assurance programmes and quality control protocols in diagnostic radiology, since large variations in dose were found for the same type of x-ray examination.

In order to assess the validity of a revised Quality Criteria Working Document and to overcome some of the limitations of the first trial, a second trial was carried out in 1991(4). Original films of chest, lumbar spine and breast radiographs were sent to an independent panel of radiologists for assessment against the image criteria. A questionnaire was employed to collect entrance surface doses and details of the radiographic equipment and technique factors in use. The results of the 1991 trial highlighted a number of important features of radiographic practice in Europe. Information concerning the technical parameters of radiographic equipment was still in many cases not sufficiently known by staff in x-ray departments. The trial demonstrated that in conventional radiology the entrance surface dose provides a useful measure of the patient dose and it confirmed that there existed wide variations in performance throughout Europe. Furthermore the results showed that radiologists find it difficult to interpret unequivocally criteria which involve some form of assessment of symmetry, field coverage and fulfilment of technical requirements. It was concluded that a compartmentalisation of image criteria was required in order to link, more consistently, the image quality, patient dose and radiographic technique.

Besides such European wide trials, reports are also becoming available concerning the experiences of clinical application of the quality criteria for conventional radiography at a national level. For example, Vaño and colleagues (5,6) have confirmed the clinical applicability of the quality criteria concept and illustrated the potential for dose reduction in Spain.

COMPUTED TOMOGRAPHY

To date no results of research studies are available to indicate to what extent radiation dose may be reduced while retaining clinical effectiveness of the examination. The basis for the current

guidelines is the supposition that the quality criteria concept, which was developed for conventional radiography, can also be used for advancing optimisation of CT examinations. Nevertheless some fundamental modifications have had to be made owing to the particular characteristics of CT, for example, patient dose during CT should not be expressed as entrance surface dose but in terms of quantities that have been specifically developed for CT, such as the weighted computed tomography dose index ($CTDI_w$) for a slice and the dose-length product (DLP) for a complete examination.

For the establishment of the quality criteria for CT extensive data were currently available on patient dosimetry and patient dose in relation to CT examinations (7-13). In addition, some information has been published concerning the relationship between dose and CT image quality (14-16). More comprehensive approaches to patient dose, diagnostic image quality and technical parameters have also been described for CT (17-19).

The elaboration of the image criteria in CT has been difficult due to the complexity of CT anatomy and technique. The image criteria that have been elaborated by the German Federal Chamber of Physicians (20) proved to be a valuable source of information. They were tested in a pilot study at the University Hospital of Aarhus for CT of the mediastinum (23 examinations) and CT of the retroperitoneal space (30 examinations) (17). The analysis showed that it is necessary to differentiate the degree of visualization of the anatomical structures by including the term visually sharp reproduction instead of just visualization of critical anatomical structures. Consequently a set of modified criteria was tested in the same institution (190 examinations) (17) and a new list of criteria was elaborated for the mediastinum and the retroperitoneal space. The results showed that nearly all of the new criteria were useful for measuring the diagnostic image quality as they were fulfilled in an acceptable amount of examinations but not always (18). These criteria were included in the first working document on CT quality criteria that was published April 1997. It was sent out for comments to professional groups, such as radiologists, radiographers, and medical physicists as well as to manufacturers and health care authorities in the member states of the European Union. This request yielded some 50 responses. The quality criteria and reference doses for CT were presented at several congresses and symposia, e.g. at ECR'97 and at the EC Workshop on Reference Doses and Quality in Medical Imaging, held October 1997 in Luxembourg. At this Workshop the University of Aarhus presented results and guidelines on image criteria for CT brain, based on 119 examinations (21). Also the first experiences with the clinical implementation of quality criteria for 102 CT brain examinations were presented by Calzado et al. and found to be useful (22).

The comments on the first working document were incorporated in the May 1998 version which was discussed at the EC-workshop on quality criteria for computed tomography, held November 1998 in Aarhus, Denmark. The workshop aimed at deriving consensus on the 1998 working document before publication. Of the 49 participants, 46 came from 12 European countries, 2 from Brazil and 1 from the USA. They represented hospitals, governments, professional bodies and manufacturers of CT scanners.

At the workshop and at ECR'99 results of a pilot trail were presented, which evaluated the quality criteria for examination of the face and sinuses, the spine, the chest (HRCT), liver and spleen, and osseous pelvis in hospitals of four countries (Denmark, The Netherlands, Switzerland and the United Kingdom).This trail showed that high radiation doses to the patient did not always imply optimal diagnostic quality. Dose reduction, especially regarding examinations of the face and sinuses and osseous pelvis, seemed to be achievable without loss of diagnostic image quality. It was concluded that the quality criteria can be used to optimise these CT procedures. As a result of this study some changes of the criteria for the liver and spleen and for osseous pelvis were included in the present guidelines.

ESTABLISHMENT OF REFERENCE DOSE VALUES

SELECTION OF REFERENCE DOSE QUANTITIES

Reference doses are intended to allow comparison of performance. In order to achieve this objective for CT, reference doses had to be expressed in terms of quantities which fulfil the following criteria:

(a) provide a meaningful indication of patient exposure, taking into account the details of scanning technique used by individual centres for particular examinations;

(b) well-defined and simple to measure or easy to determine in order to encourage widespread use at CT centres of all sizes and levels of sophistication;

(c) applicable to all current and new types of scanner and to all common techniques, including helical scanning;

(d) consistency of approach with other reference doses and dose descriptors already in widespread use.

There are a number of dosimetric quantities that are employed routinely under various circumstances to characterise exposure from CT scanners. One of the most practical measurements concerns the computed tomography dose index (CTDI) (23). This quantity is simple and can easily be determined free-in-air on the axis of rotation of the scanner for a single scan ($CTDI_{air}$). This approach has formed the basis for national surveys in several countries. By itself, $CTDI_{air}$ is only a coarse indicator of patient exposure for an examination, for example, the relationship between $CTDI_{air}$ and effective dose for a standard examination varies by up to a factor three between models of scanner as a result of inherent differences in design, and in particular the use of shaped beam filtration (24). $CTDI_{air}$ therefore is not well-suited for use as a reference dose quantity since the setting of a single level for a given procedure would not equitably dictate practice for all types of scanner. $CTDI_{air}$ can, however, still be an important element in the implementation of patient dosimetry.

Effective dose (25) is certainly a useful indicator of patient exposure, although it is also not particularly suitable as a reference dose quantity since it can not be measured directly and its definition may be subject to further changes.

Measurements with phantoms offer the advantage of taking into account differences in dose distribution arising from scanner design, particularly if measurements are not confined to the phantom surface. However, any such dosimetric approach should utilise well-defined and commonly available phantoms in order to gain wide acceptance. For a series of multiple scans with constant separation, the *multiple scan average dose* (MSAD) (23) is an indication of the magnitude of the dose along the length of the scanned volume at a particular radial depth in a phantom . This quantity has been recommended by the American Association of Physicists in Medicine (AAPM) in relation to the specification and acceptance testing of CT scanners (26) and has been reported in surveys of CT practice in the USA (27). MSAD is equal to CTDI when the distance between scans is equal to the slice thickness (23).

Another quantity in wide-spread use is the particular definition of CTDI given by the Food and Drug Administration (FDA), i.e. $CTDI_{FDA}$ (28), in relation to measurements in a phantom for the purposes of compliance testing of CT systems in the USA. It involves the integration of D(z) over a distance of 14 times the slice thickness, where D(z) is the dose at a point z on any line parallel to the z (rotational) axis for a single slice of nominal thickness T.
Under requirements of FDA in the USA, manufacturers of CT scanners are obliged to report values of $CTDI_{FDA}$ for all modes of operation. Values of such measurements in standard CT dosimetry phantoms are quoted in terms of absorbed dose in PMMA.

For a given type of scanner and CT dosimetry phantom (head or body), values of $CTDI_{FDA}$ measured simultaneously at the surface and the centre of the phantom may vary by up to a factor of three. Variations in this ratio between scanners reflect differences in equipment design,

and in particular the shape of the beam filtration.
Although measurements of $CTDI_{FDA}$ represent an established body of data, this quantity is not ideal, however, from the point of view of practical dosimetry. Not only is it expressed in terms of dose to PMMA, which requires the introduction of an additional calibration factor together with its associated uncertainty, but also the length of integration (14 slice thicknesses) varies in absolute terms between settings and is difficult to realise experimentally.

In practice, it is more convenient to measure CTDI over a fixed length of integration using a pencil ionisation chamber with an active length of 100 mm. This provides a measurement of $CTDI_{100}$, expressed in terms of absorbed dose to air (mGy). When measured in phantoms, such values are larger than corresponding values of $CTDI_{FDA}$ under similar conditions of exposure, with this difference being most significant at small slice thicknesses (Table 1, Appendix I to Chapter 1). Although the ratio of absorbed doses in air and PMMA is approximately 1.1 for the radiation qualities commonly found in CT, this difference is lower (29) for measurements with slice thicknesses in excess of 7 mm by the relatively shorter lengths of integration for $CTDI_{100}$ in comparison with $CTDI_{FDA}$; conversely, the difference is exacerbated at smaller slice thicknesses by the relatively longer lengths of integration for $CTDI_{100}$. The definition of $CTDI_{100}$ in this guidelines is consistent with the IEC standard on computed tomography (30). Comparing the properties of the various dose quantities, it has been decided to take the $CTDI_{100}$ at the surface and centre of the head or body CT dosimetry phantoms as an adequate basis for specifying reference doses for CT. From these measurements a weighted CTDI ($CTDI_w$), representing the average dose to a single slice, and an associated dose-length product (DLP) for a complete examination, can be derived. More details about the definition of these quantities are given in Appendix I to Chapter 1.

DERIVATION OF REFERENCE DOSES VALUES

In concept, reference dose values for diagnostic medical exposures are essentially investigation levels which relate to typical practice rather than to individual patients. Such doses are not intended to inhibit the development of sound clinical practice. Reference dose values should be examination-specific and be set to provide an indication of potentially unacceptable practice. They may, for example, be based on the results of large-scale surveys which take into account the variation in performance between centres (31). This approach has been successfully applied to common conventional x-ray examinations in the UK, whereby examination-specific reference dose values were set pragmatically at the third quartile values of the distributions of mean doses observed for representative samples of patients at each centre in a national survey (32). Accordingly, the top dose quartiles have been taken to represent the bounds of potentially unacceptable practice; centres with doses above this level of the distributions are encouraged to carry out urgent investigations with a view to correct action or provide a thorough clinical justification for the use of exceptionally high doses.

Levels of dose from CT examinations depend on the general technique and equipment in use, and also the clinical and physical characteristics of the patient. Wide-scale survey data relating to CT practice may also provide a convenient means for deriving initial values of reference dose quantities for CT. Dose data for some routine examinations (head, chest, abdomen and pelvis) are available from a national survey in the UK at the beginning of the 1990's (8). Distributions are shown in Figures 1 and 2 illustrating the variations in typical values of $CTDI_w$ per single slice and DLP per complete examination, respectively, observed between CT centres for routine head examinations (8). For completeness, the values of $CTDI_{air}$ underlying these data are shown in Figure 3 in order to demonstrate that this quantity is more dependent on scanner design and hence shows greater variation than $CTDI_w$. This is why a single value of $CTDI_{air}$ is impractical as a universal reference dose quantity, as discussed above. More recent information concerning some specific examinations (face and sinuses, vertebral trauma, HRCT of the lung, liver and spleen, and osseous pelvis) have been provided by a pilot study of the quality criteria (33). More detailed analyses of the survey data described above are given in Tables 1 and 2, including quartile values for the distributions of $CTDI_w$ and DLP, respectively. Accordingly, initial reference

dose values for CT, proposed on the basis of the third quartile values from these distributions, are given in Table 3. Effective dose can be calculated from the operational dose values ($CTDI_{air}$ or DLP) thus enabling the different examinations to be compared meaningfully taking into account the relative radiosensitivities of the body regions involved.

The suitability of the initial reference dose values proposed in Table 3 should be checked by means of a wide-scale trial. Consequently the setting and review of reference dose values should be seen as a continuing process in order to promote continous improvement over time.

LIST OF REFERENCES FOR CHAPTER 2

1. European Guidelines on Quality Criteria for Diagnostic Radiographic Images. Report EUR 16260 (1996)

2. European Guidelines for Quality Criteria for Diagnostic Radiographic Images in Paediatrics. EUR 16261 (1996)

3. Maccia C, Wall BF, Padovani R, Shrimpton PC, and Husson B. Results of a trial set up by a study group of the radiation protection programme of the CEC. In: Optimisation of image quality and patient exposure in diagnostic radiology. British Institute of Radiology Report 20, Edited by Moores BM, Wall BF, Eriskat H, and Schibilla H, pp 242-246 (London, BIR) (1989)

4. Maccia C, Moores BM, and Wall BF. The 1991 trial on quality criteria for diagnostic radiogarphic images, detailed results and findings, Report EUR 16635 (1997)

5. Vaño E, Oliete S, González L, Guibelalde E, Velasco A, and Fernández JM. Image quality and dose in lumbar spine examinations: results of a 5 year quality control programme following the European quality criteria trial. British Journal of Radiology, **68**, 1332-1335 (1995)

6. Vaño E, Guibelalde E, Morillo A, Alvarez-Pedrosa CS, and Fernández JM. Evaluation of the European image quality criteria for chest examinations. British Journal of Radiology, **68**, 1349-1355 (1995)

7. Panzer W, Scheurer C, and Zankl M. Dose to patients in computed tomographic examinations: results and consequences from a field study in the Federal Republic of Germany. In: Optimisation of image quality and patient exposure in diagnostic radiology. British Institute of Radiology Report 20, Edited by Moores BM, Wall BF, Eriskat H, and Schibilla H, pp 185-187 (London, BIR) (1989)

8. Shrimpton PC, Jones DG, Hillier MC, Wall BF, Le Heron JC, and Faulkner K. Survey of CT practice in the UK. Part 2: Dosimetric aspects. Chilton, NRPB-R249 (London, HMSO) (1991)

9. Jones DG and Shrimpton PC. Survey of CT practice in the UK. Part 3: Normalised organ doses calculated using Monte Carlo techniques. Chilton, NRPB-R250 (1991)

10. Zankl M, Panzer W and Drexler G. The calculation of dose from external photon exposures using reference human phantoms and Monte Carlo methods. Part VI: Organ doses from computed tomographic examinations. GSF-Bericht 30/91 (Neuherberg, Gesellschaft für Strahlen- und Umweltforschung) (1991)

11. Shrimpton PC and Wall BF. The increasing importance of x-ray computed tomography as a source of medical exposure. Radiation Protection Dosimetry, **57** (1-4), 413-415 (1995)

12. Unnik JG van, Broerse JJ, Geleijns J, Jansen JThM, Zoetelief J, Zweers D. Survey of CT techniques and absorbed dose in various Dutch hospitals. British Journal of Radiology, **70**, 367-371 (1997)

13. Olerud HM. Analysis of factors influencing patient doses from CT in Norway. Radiation Protection Dosimetry, **71**, 123-133 (1997)

14. Dalla Palma L and Pozzi-Mucelli RS. Image quality criteria for computed tomography. In: Optimisation of image quality and patient exposure in diagnostic radiology. British Institute of Radiology Report 20, Edited by Moores BM, Wall BF, Eriskat H and Schibilla H, pp 72-78 (London, BIR) (1989)

15. Carvalho AF, Oliveira AD, Alves JG, Carreiro JV, Jensen LC and Jessen KA. Quality control in computed tomography performed in Portugal and Denmark. Radiation Protection Dosimetry, **57** (1-4), 333-337 (1995)

16. Olerud HM, Olsen JB and Skretting A. An anthropomorphic phantom for receiver operating characteristic studies in CT imaging of liver lesions. British Journal of Radiology, **72**, 35-43 (1999)

17. Albrechtsen J, Hansen J, Jensen LC, Jessen KA and Jurik AG. Quality control and image quality criteria in computed tomography. Radiation Protection Dosimetry, **57** (1-4), 125-127 (1995)

18. Jurik AG, Jessen KA and Hansen J. Image quality and dose in computed tomography. European Radiology, **7**, 77 - 81 (1997)

19. Jurik AG, Fiirgaard B, Jensen JH, Jessen KA and Hansen J. Image quality criteria and patient dose in CT of the brain. British Journal of Radiology (to be published)

20. Leitlinien der Bundesärztekammer zur Qualitätssicherung in der Computertomographie. Dt. Ärztebl. **89**: Heft 49 (1992) (English translation: Guidelines of the Federal Chamber of Physicians on quality assurrence in computed tomography. Internal Document CEC XII/354/92-EN)

21. Jurik AG, Bongartz B, Golding SJ, Leonardi M. The quality criteria for computed tomography. Radiation Protection Dosimetry, **80**, 49-53 (1998)

22. Calzado A, Rodríguez R and Muñoz A. Quality criteria implementation for brain computed tomography examinations. Radiation Protection Dosimetry, **80**, 65-68 (1998)

23. Shope TB, Gagne RM and Johnson GC. A method for describing the doses delivered by transmission x-ray computed tomography. Medical Physics, **8** (4), 488-495 (1981)

24. Shrimpton PC and Edyvean S. CT scanner dosimetry. British Journal of Radiology **71**, 1 - 3 (1998)

25. ICRP Publication 60, 1990 Recommendations of the International Commission on Radiological Protection, Annals of the ICRP Vol. **21** Nos. 1-3 (Pergamon Press, Oxford) (1991)

26. AAPM. Specification and acceptance testing of computed tomography scanners. Report No 39 (New York, AAPM) (1993)

27. Conway BJ, McCrohan JL, Antonsen RG, Rueter FG, Slayton RJ and Suleiman OH. Average radiation dose in standard CT examinations of the head: results of the 1990

NEXT survey. Radiology, **184**, 135-140 (1992)

28. Department of Health and Human Services, Food and Drug Administration. 21 CFR Part 1020: Diagnostic x-ray systems and their major components; amendments to performance standard; Final rule. Federal Register, **49**, 171 (1984)

29. Edyvean S, Lewis MA, Britten AJ, Carden JF, Howard GA and Sassi SA. Type testing of CT scanners: methods and methodology for assessing imaging performance and dosimetry. MDA Evaluation Report MDA/98/25. London, Medical Devices Agency (1998)

30. International standard of IEC 60601-2-44: Medical electrical equipment - Part 2-44: Particular requirements for the safety of x-ray equipment for computed tomography (1999)

31. IAEA. International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources. International Atomic Energy Agency Safety Series No 115 Vienna, IAEA (1996)

32. NRPB. Medical exposure: Guidance on the 1990 Recommendations of ICRP. Documents of the NRPB, **4**, No 2, 43-74 (1993)

33. Jurik AG, Petersen J, Bongartz, Golding SJ, Leonardi M, van Meerten PvE, Geleijns J, Jessen KA, Panzer W, Shrimpton P, Tosi G. Clinical use of image quality criteria in computed tomography related to radiation dose. A pilot study. European Radiology (to be submitted)

Table 1 Analysis of estimated values of $CTDI_w$ from surveys of CT practice, expressed in terms of absorbed dose to air

Examination type	$CTDI_w$ (mGy)							
	Sample size	Mean	SD	Min	25%	Median	75%	Max
Head[a]	102	50.0	14.6	21.0	41.9	49.6	57.8	130
Face and sinuses[b]	20	31.7	15.9	-	19.9	28.0	35.2	-
Vertebral trauma[b]	20	44.1	21.5	-	29.4	39.7	68.3	-
Chest[a]	88	20.3	7.6	4.0	15.2	18.6	26.8	46.4
HRCT of lung[b]	20	31.7	14.9	-	19.4	31.0	35.0	-
Abdomen[a]	91	25.6	8.4	6.8	18.8	24.8	32.8	46.4
Liver and spleen[b]	15	26.1	11.3	-	15.4	25.0	34.0	-
Pelvis[a]	82	26.4	9.6	6.8	18.5	26.0	33.1	55.2
Osseous pelvis[b]	16	24.7	17.8	-	14.8	20.0	24.6	-

Notes:
a. Estimated values from UK survey data[(8)]
b. Dose data from Pilot Study [(33)]

Table 2 Analysis of estimated values of DLP from surveys of CT practice on the basis of absorbed dose to air (mGy cm)

Examination type	DLP (mGy cm)							
	Sample size	Mean	SD	Min	25%	Median	75%	Max
Head[a]	102	882	332	231	673	795	1045	2087
Face and sinuses[b]	20	259	118	158	180	204	353	506
Vertebral trauma[b]	20	392	214	40	254	353	455	914
Chest[a]	88	517	243	72	349	490	649	1304
HRCT of lung[b]	20	200	71	100	136	199	278	312
Abdomen[a]	91	597	281	115	415	525	774	1874
Liver and spleen[b]	20	658	293	151	485	651	894	1181
Pelvis[a]	82	443	233	68	266	416	566	1324
Osseous pelvis[b]	16	514	426	43	225	465	518	1758

Notes:
a. Estimated values from UK survey data[(8)]
b. Dose data from Pilot Study [(33)]

Table 3 Proposed reference dose values for routine CT examinations on the basis of absorbed dose to air

Examination	Reference dose value	
	$CTDI_w$ (mGy)	DLP (mGy cm)
Routine head[a]	60	1050
Face and sinuses[a]	35	360
Vertebral trauma[b]	70	460
Routine chest[b]	30	650
HRCT of lung[b]	35	280
Routine abdomen[b]	35	780
Liver and spleen[b]	35	900
Routine pelvis[b]	35	570
Osseous pelvis[b]	25	520

Notes:
a. Data relate to head phantom (PMMA, 16 cm diameter)
b. Data relate to body phantom (PMMA, 32 cm diameter)

Figure 1 Histogram of $CTDI_w$ data for routine head examinations in the UK, on the basis of absorbed dose to air

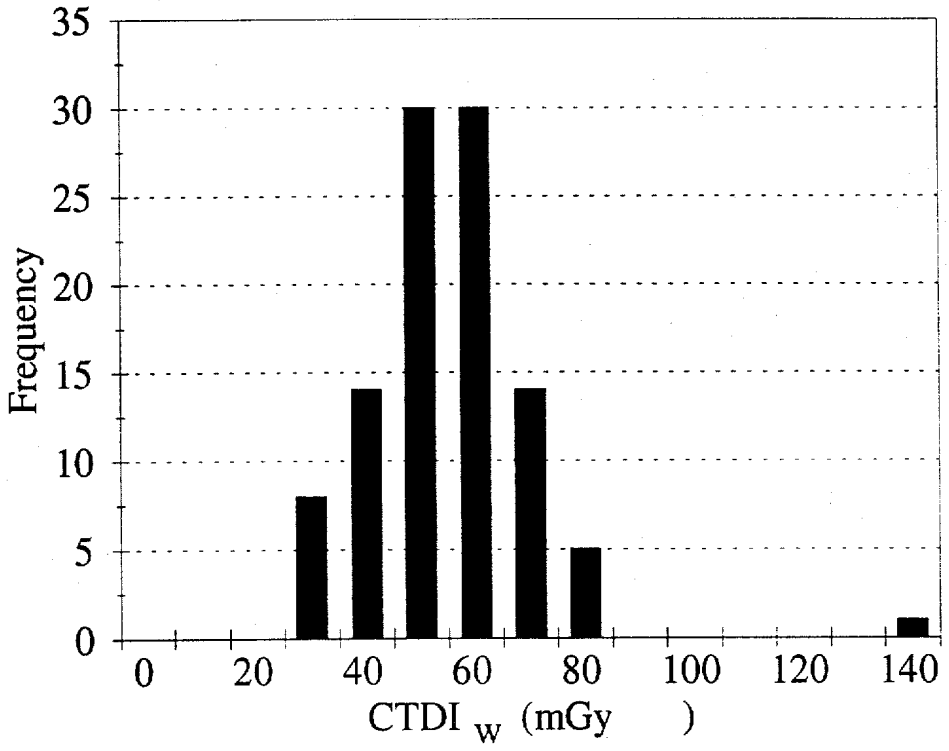


Figure 2 Histogram of DLP data for routine head examinations in the UK, on the basis of absorbed dose to air

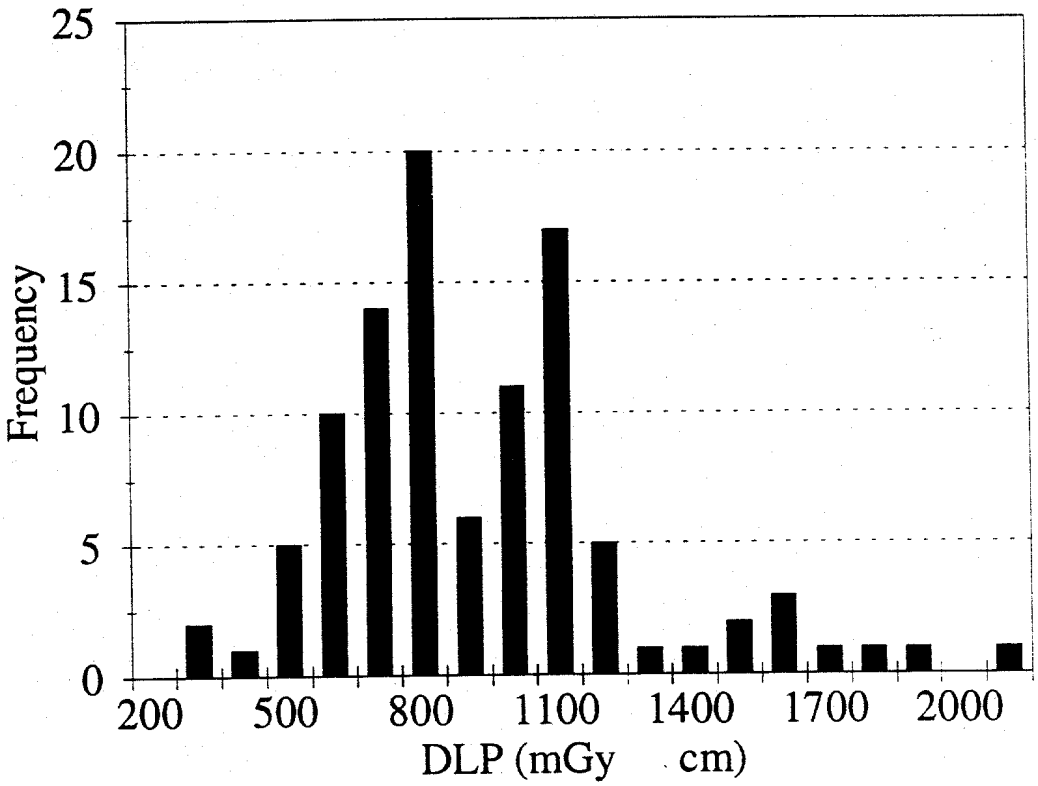
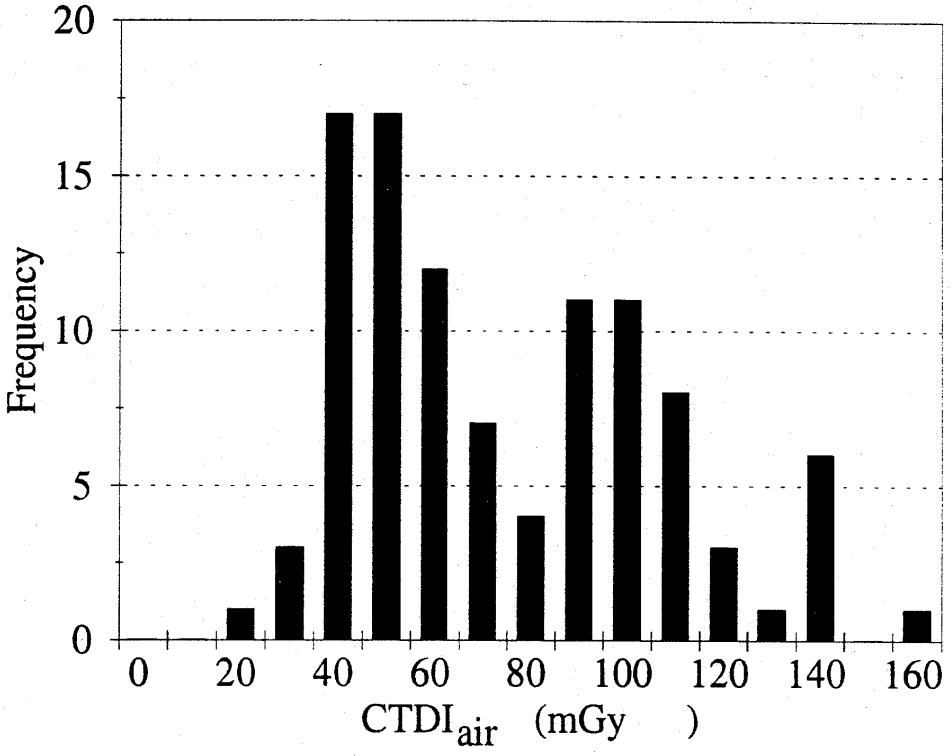


Figure 3 Histogram of $CTDI_{air}$ data for routine head examinations in the UK, expressed in terms of absorbed dose to air



Chapter 2
APPENDIX I

CT SCANNER DOSIMETRY DATA

Data are tabulated below for a selection of scanner models relating to typical values of the normalised dose quantities ${}_nCTDI_{air}$ and ${}_nCTDI_w$, and the factor $P_{H\ or\ B}$, as described in Appendix I to Chapter 1. These illustrative data may be used in the absence of measured data to provide broad estimates of the reference dose quantities for CT. Further data relating to a more comprehensive range of scanners are available in the reference database on CT dosimetry that has been published on the Internet (http://www.efomp.org).

Examples of CT Scanner Dosimetry Data (expressed in terms of absorbed dose to air)

Manufacturer	Model	Applied potential (kV)	Focus-axis distance (mm)	Slice thickness (mm)	$_nCTDI_{air}$ mGy /mAs	PMMA Head phantom (16 cm diameter)		PMMA Body phantom (32 cm diameter)	
						$_nCTDI_w$ mGy/mAs	P_H	$_nCTDI_w$ mGy/mAs	P_B
Siemens	AR.HP	130	510	10	0.335	0.252	0.75	0.128	0.38
	Hi Q	133	700	10	0.195	0.161	0.83	0.093	0.48
	Plus S	120	700	10	0.128	0.110	0.86	0.062	0.48
		137	700	8	0.161	-	-	0.082	0.51
GE	Pace	120	525	10	0.344	0.200	0.58	0.094	0.27
	Max 640	120	525	10	0.258	0.158	0.61	0.064	0.25
	9800	120	630	10	0.204	0.143	0.70	0.063	0.31
Philips	LX	120	606	10	0.200	0.160	0.80	0.081	0.41
	CX/Q	120	606	10	0.172	0.149	0.87	0.070	0.41
	SR	120	606	10	0.204	0.152	0.75	0.082	0.40
Picker	PQ 2000[a]	130	640	10	0.338	0.287	0.85	0.150	0.44
CGR	12000	130	750	10	0.113	0.086	0.76	0.087	0.77

Note:
a: Full field (Filter 0 used)

For further information see Reference Database on CT dosimetry: http://www.efomp.org

Chapter 3

QUALITY CRITERIA IMPLEMENTATION AND AUDIT GUIDELINES

Table of Contents

QUALITY CRITERIA IMPLEMENTION AND AUDIT GUIDELINES

The quality criteria are designed to be easily applied in practice in any x-ray department without the need for special equipment apart from that needed for measuring or estimating the dose to the patient. They are intended to provide a demonstrably achievable standard of good practice both in terms of a satisfactory level of image quality and an acceptably low radiation dose to the patient.

However, the quality criteria will only be of real benefit to an x-ray department if they allow inadequate levels of performance to be readily identified and corrected. The impact of applying the quality criteria in a particular x-ray department in terms of the level of improvement in performance achieved, can only be properly assessed through a correctly structured process of medical audit.

The essential components of the medical audit process can be summarised as:

Set standards
Check compliance
Correct bad practice
Set new standards
Repeat

The quality criteria essentially provide the initial "standards" for image quality and patient dose audit: a special case of "medical" audit.

More detailed steps in the audit process specific to this special case are:

1. Choose type of CT examination and CT equipment to audit.

2. Take random sample of at least 10 standard-sized patients (60-80 kg).

3. Perform chosen type of CT examination on each patient using the established techniques.

4. Record all the technique and equipment parameters for each examination. (See example of a questionnaire in Appendix I to this chapter for relevant details to be recorded).

5. Record the $CTDI_W$ and DLP for each examination using the methods described in Appendix I of Chapter 1. Compare the mean value for the sample of at least 10 standard-sized patients with the corresponding reference dose listed in the quality criteria.

6. At least two observers check compliance of each CT examination with the image criteria independently. Appendix II to this chapter contains examples of image criteria assessment forms for the 5 types of examination evaluated in a pilot trial of quality criteria. As well as providing a system for scoring compliance with the image criteria and the visibility of important image details, these forms also include a system for scoring more general aspects of the image, such as noise, spatial resolution and diagnostic acceptability. Similar forms can be elaborated for other types of examinations for which quality criteria are provided in the guidelines.

   To help in judging these image features, both during this audit process and more generally at any time, x-ray departments should consider having available a set of "ideal" hard copies of examinations in which all quality aspects are optimised and against which any other examination, can be directly visually compared. It is essential, of course, that the "ideal" examinations can be produced with a dose to the patient

below the corresponding diagnostic reference value.

7. Identify where the standard (image quality or dose criteria) are being not met.

8. Investigate the cause(s) of any persistent non-compliance with the criteria. The "Examples of Good Radiographic Technique" may be useful to help identify those aspects of the established technique or equipment which are responsible for non-compliance.

9. Take corrective action by changing techniques or equipment in a manner likely to remedy the occurrence of non-compliance.

10. After a short period of using the revised techniques or equipment, repeat steps 2-7.

11. If no improvement, repeat steps 8-10.

12. If initial standards (quality criteria) are now being met in full, consider improving standards, for example, by setting lower reference doses in line with the optimisation principle ALARA (As Low as Reasonably Achievable).

To help establish a more uniform and more widespread level of performance in diagnostic radiology, it would be desirable to extend the audit process to include independent observers, external to the x-ray department being audited, and progressively to apply the process to larger groupings than individual x-ray departments.

Chapter 3
APPENDIX I

SAMPLE QUESTIONNAIRE FOR RECORDING DATA ON EQUIPMENT, RADIOGRAPHIC TECHNIQUE AND DOSE

QUESTIONNAIRE

Type of examination:_____

A) RADIOGRAPHIC TECHNIQUE ⇒ to be filled in by the radiographer/radiologist

A.1. CT scanner

- Manufacturer/Type: ...../.....
- Year of manufacture: .....

A.2. Patient position

- Supine ..... ☐
- Prone ..... ☐
- Other position, describe: .....

A.3. Gantry tilt

- None ..... ☐
- Cranial, degree..... ☐
- Caudal, degree..... ☐

A.4. Hard copy facilities

- Laser camera — Manufacturer/Type: ...../.....
  In use since (date): .....
- Film — Manufacturer/Type: ...../.....
- Film Processor — Manufacturer/Type: ...../.....
  Processing Time: .....sec. ☐
  Developer Temperature: .....°C ☐

B) PATIENT RELATED DATA ⇒ to be filled in by the radiographer/radiologist

B.1. Age ..... years ☐

B.2. Sex ..... F ☐ M ☐

B.3. Height ..... cm ☐

B.4. Weight ..... kg ☐

C) IMAGE VIEWING DATA ⇒ to be filled in by the radiographer/radiologist

Settings	Sequence 1	Sequence 2	Sequence 3
C1) Reconstruction algorithm			
C2) Field of view			
C3) Window width			
C4) Window level			

D) DOSE RELATED DATA

D.I) DOSE RELATED DATA ⇒ to be filled in by the radiographer/radiologist

Details of technique	Sequence 1	Sequence 2	Sequence 3
Exposure factors			
Tube voltage (kV)			
Tube current x exposure time (mAs/slice) [1]			
Tube current x total acquisition time (mAs total) [2]			
Slice thickness (mm)			
Couch increment (table feed) (mm)			
Number of slices			

[1] For serial scanning
[2] For helical scanning

D.II) DOSE RELATED DATA ⇒ to be filled in by the physicist

Quantity	Sequence 1	Sequence 2	Sequence 3
Tube filtration setting [3]			
${}_nCTDI_w$ [4] (mGy/mAs)			
$CTDI_w$ (mGy)[5]			
Dose-length product (mGy x cm)			
Total dose-length product (mGy x cm) [6]			
Phantom diameter (cm)			

[3] List if this can be varied
[4] The normalized weighted CT dose index ${}_nCTDI_w$ has to be determined for the radiation quality (tube voltage, filtration) and beam geometry (focus to axis distance, FOV, beam shaping) as used in the respective sequence
[5] Per slice for serial scanning and per rotation for helical scanning
[6] Sum of all sequences

Chapter 3
APPENDIX II

EXAMPLES OF IMAGE QUALITY ASSESSMENT FORMS

Face and sinuses

Spine

Chest, HRCT

Liver and spleen

Osseous pelvis

FACE AND SINUSES

Name of radiologist/radiographer: _____

Patient number: _____ Hospital code: _____

Image quality criteria	Sequence 1		Sequence 2		Total examination	
	Yes	No	Yes	No	Yes	No
Visualization of 1. Entire face from palate to the top of the frontal sinus						
2. Vessels after intravenous contrast media						
Critical reproduction 1. Visually sharp reproduction of the cortical and trabecular bone structures						
2. Visually sharp reproduction of the frontal sinuses						
3. Visually sharp reproduction of the sphenoid sinuses						
4. Visually sharp reproduction of the orbitae						
5. Reproduction of the globe, optic nerve and orbital muscles						
6. Visually sharp reproduction of the ethmoid						
7. Visually sharp reproduction of the maxilla and its sinuses						
8. Visually sharp reproduction of the nasal cavity						
9. Visually sharp reproduction of the rhinopharynx						

It is important for every criterion to evaluate if it is fulfilled or not. **If a criterion cannot be evaluated it should be clearly marked by NA in the yes box.**

General assessment:

- **Acceptable noise** ..... * ☐
- **Acceptable spatial resolution** ..... * ☐
- **Diagnostic acceptability** ..... # ☐

* + optimum; ↑ too much; ↓ too little

\# 1: fully acceptable; 2: probably acceptable; 3: only acceptable under limited conditions; 4: unacceptable (give reasons)

Comments_____

VERTEBRA AND PARAVERTEBRAL STRUCTURES

Name of radiologist/radiographer: _____

Patient number: _____ Hospital code: _____

Image quality criteria	Sequence 1		Sequence 2		Total examination	
	Yes	No	Yes	No	Yes	No
Visualization of 1. The entire region of suspected pathology						
2. Vessels after intravenous contrast media						
3. Spinal cord and nerve roots after intrathecal injection of contrast media (CT-myelography)						
Critical reproduction 1. Visually sharp reproduction of the cortical and trabecular vertebral bone						
2. Visually sharp reproduction of the intervertebral joints						
3. Visually sharp reproduction of the intervertebral disk profiles						
4. Visually sharp reproduction of the intervertebral radicular canals						
5. Reproduction of thecal sac						
6. Visually sharp reproduction of the spinal cord or canda equina (CT-myelography)						
7. Reproduction of the paravertebral ligaments						
8. Visually sharp reproduction of the paravertebral muscles						
9. Reproduction of the main vessels and perithecal venous plexuses after intravenous contrast media						

It is important for every criterion to evaluate if it is fulfilled or not. **If a criterion cannot be evaluated it should be clearly marked by NA in the yes box.**

General assessment:

- **Acceptable noise** ..... * ☐
- **Acceptable spatial resolution** ..... * ☐
- **Diagnostic acceptability** ..... # ☐

* + optimum; ↑ too much; ↓ too little

\# 1: fully acceptable; 2: probably acceptable; 3: only acceptable under limited conditions; 4: unacceptable (give reasons)

Comments_____

Name of radiologist/radiographer: _____

Patient number: _____ Hospital code: _____

Image quality criteria	Sequence 1		Sequence 2		Total examination	
	Yes	No	Yes	No	Yes	No
Visualization of 1. Entire field of lung parenchyma						
Critical reproduction 1. Visually sharp reproduction of the lung parenchyma						
2. Visually sharp reproduction of pulmonary fissures						
3. Visually sharp reproduction of secondary pulmonary lobular structures such as interlobular arteries						
4. Visually sharp reproduction of large and medium sized pulmonary vessels						
5. Visually sharp reproduction of small pulmonary vessels						
6. Visually sharp reproduction of large and medium sized bronchi						
7. Visually sharp reproduction of small bronchi						
8. Visually sharp reproduction of the pleuromediastinal border						
9. Visually sharp reproduction of the border between the pleura and the thoracic wall						

It is important for every criterion to evaluate if it is fulfilled or not. **If a criterion cannot be evaluated it should be clearly marked by NA in the yes box.**

General assessment:

- **Acceptable noise** ..... * ☐
- **Acceptable spatial resolution** ..... * ☐
- **Diagnostic acceptability** ..... # ☐

* + optimum; ↑ too much; ↓ too little

1: fully acceptable; 2: probably acceptable; 3: only acceptable under limited conditions; 4: unacceptable (give reasons)

Comments_____

LIVER AND SPLEEN

Name of radiologist/radiographer: _____

Patient number: _____ Hospital code: _____

Image quality criteria	Sequence 1		Sequence 2		Sequence 3		Total examination	
	Yes	No	Yes	No	Yes	No	Yes	No
Visualization of 1. Entire liver								
2. Entire spleen								
3. Vessels after intravenous contrast media								
Critical reproduction 1. Visually sharp reproduction of the liver parenchyma and intrahepatic portal veins								
2. Visually sharp reproduction of the liver veins								
3. Visually sharp reproduction of the structures of the liver hilus								
4. Visually sharp reproduction of the common hepatic duct								
5. Reproduction of the ductus choledochus (common bile duct) in the pancreatic parenchyma								
6. Reproduction of the gallbladder wall								
7. Visually sharp reproduction of the splenic parenchyma								
8. Visually sharp reproduction of the splenic artery								
9. Visually sharp reproduction of the extrahepatic portal vein system including v. lienalis and v. mesenterica sup.								
10. Visually sharp reproduction of the aorta and inferior vena cava								
11. Visually sharp reproduction of the origin of the coeliac trunk								
12. Visually sharp reproduction of the mesenteric artery								

It is important for every criterion to evaluate if it is fulfilled or not. **If a criterion cannot be evaluated it should be clearly marked by NA in the yes box.**

General assessment:

- **Acceptable noise** ..... * ☐
- **Acceptable spatial resolution** ..... * ☐
- **Diagnostic acceptability** ..... # ☐

* + optimum; ↑ too much; ↓ too little

\# 1: fully acceptable; 2: probably acceptable; 3: only acceptable under limited conditions; 4: unacceptable (give reasons)

Comments_____

OSSEOUS PELVIS

Name of radiologist/radiographer: _____

Patient number: _____ Hospital code: _____

Image quality criteria	Sequence 1		Sequence 2		Total examination	
	Yes	No	Yes	No	Yes	No
Visualization of 1. Whole pelvic ring						
2. Hip(s) including the trochanter region						
3. Sacroiliac joints						
4. Pubic symphysis						
Critical reproduction 1. Visually sharp reproduction of the pelvic bones						
2. Visually sharp reproduction of the hip joint(s)						
3. Visually sharp reproduction of the sacroiliac joints						
4. Visually sharp reproduction of the pubic symphysis						
5. Visually sharp reproduction of the pelvic musculature						

It is important for every criterion to evaluate if it is fulfilled or not. **If a criterion cannot be evaluated it should be clearly marked by NA in the yes box.**

General assessment:

- **Acceptable noise** ..... * ☐
- **Acceptable spatial resolution** ..... * ☐
- **Diagnostic acceptability** ..... # ☐

* + optimum; ↑ too much; ↓ too little

\# 1: fully acceptable; 2: probably acceptable; 3: only acceptable under limited conditions; 4: unacceptable (give reasons)

Comments_____

Chapter 4

GLOSSARY

This glossary contains descriptions of commonly-used technical terms in CT as an aid to understanding the Guidelines. The bold-faced typed words in the explanatory text indicates that they occur elsewhere in the glossary.

artefact (structured noise): The appearance in the CT image of details not present in the scanned object. The main components of structured noise are due to a form of **partial volume effect** and to **beam hardening**. Both effects usually result in streaking artefacts, which are observed in regions of high contrast when there is a sharp discontinuity in object density, such as at air-tissue, air-bone and metal-tissue boundaries. Streaking will also arise from mechanical misalignment within the scanner and, in clinical practice, from patient motion and the use of high-density contrast media.

attenuation: Reduction of the radiation **intensity**, upon passage through matter, resulting from all types of interaction.

back projection: Mathematical procedure for the reconstruction of the CT image, based on the smearing of the individual **rays** within a view (projection) back along the direction in which they were measured. Spatial filtration (**convolution**) of the **raw data** is necessary before back projection in order to reduce **artefacts**.

beam hardening: The process of filtration of a polychromatic beam by the preferential absorption of lower energy photons in tissue, with a subsequent increase in effective energy. The associated artefacts are of particular significance in **quantitative computed tomography (QCT)**.

calibration of a CT-scanner: Correction procedures used to take account of variations in beam intensity or **detector** efficiency in order to achieve homogeneity within the field of view and accuracy of **CT number**. Calibration procedures include scanning air or an appropriate **test phantom**.

collimation: Geometrical limitation of the extent of the radiation beam in the z-direction.

computed tomography dose index (CTDI): Integral along a line parallel to the axis of rotation (z) of the **dose profile** (D(z)), measured free-in-air or in a **CT dosimetry phantom** for a single slice, divided by the **nominal slice thickness** (T):

$$CTDI = \frac{1}{T}\int_{-\infty}^{+\infty} D(z)dz \qquad (mGy)$$

In practice, it is convenient to use a pencil ionisation chamber with an active length of 100 mm so as to provide a measurement of $CTDI_{100}$ (mGy to air).

computed tomography number (CT number): Number used to represent the mean x-ray attenuation associated with each elemental area of the CT image. Numbers are normally expressed in terms of **Hounsfield units (HU)**. Measured values of **attenuation** are transformed into **CT numbers** using the international Hounsfield scale:

$$CT\ number = \frac{\mu_{material} - \mu_{water}}{\mu_{water}} 1000 \qquad (HU)$$

where μ is the effective **linear attenuation coefficient** for the x-ray beam.
The CT number scale is defined so that water has a value of 0 HU and air a value of -1000 HU.

contrast: In relation to the radiation emerging from an irradiated object, if the photon fluence at some reference point is Φ_0, and at an adjacent point is Φ_1, the contrast can be defined as $(\Phi_1 - \Phi_0) / \Phi_0$, or

$\Delta\Phi/\Phi_0$. Contrast can also be expressed in terms of energy fluence or exposure.
contrast enhancement: Administration of intraveneous or intraarterial contrast increase the visibility of low contrast structures due to increased density of vessels and organs/tissue containing contrast media.

contrast resolution: See **low contrast resolution**.

convolution: The mathematical process by which **raw data** undergo spatial filtration prior to **back projection**.

couch increment: Distance by which position of patient couch (table) is changed between individual slices in serial scanning or the distance the couch position is changed during one 360° rotation of the tube during helical scanning.

CT dosimetry phantoms: Cylinders of **polymethylmethacrylate** (**PMMA**) used for standard measurements of dose in CT, having a diameter of 16 cm (head phantom) or 32 cm (body phantom) and a length of at least 14 cm. The phantoms are constructed with removable inserts parallel to the axis to allow the positioning of a dosemeter at the centre and 1 cm from the outer surface (periphery).

CT number: Abbreviation for **computed tomography number**.

CTDI: Abbreviation for **computed tomography dose index**.

$CTDI_{air}$: Value of **CTDI** determined free-in-air.

$CTDI_w$: See **weighted CTDI**.

detector: A single element of a **detector array**, which produces an electrical or light signal in response to stimulation by x-rays.

detector array: The entire assembly of **detectors**, including their interspace material, arranged along an arc or circumference (depending on scanner technology) of a circle centred on the axis of rotation.

detector efficiency: for each **detector** contained in a **detector array**, the ratio between the number of pulses recorded and the number of x-ray photons incident on the detector.

detector width: In a **detector array**, the distance between the two opposite faces of any single **detector**.

diagnostic reference level: Advisory dose levels set by professional bodies to prompt local reviews of practice if consistently exceeded.

display matrix: The array of rows and columns of **pixels** in the displayed image, typically between 512 x 512 and 1024 x 1024. It may be equal to or larger than the size of the **reconstruction matrix** due to **interpolation** procedures.

dose descriptor: measurable parameter, such as **$CTDI_{air}$**, **$CTDI_w$** or **DLP**, from which the **effective dose** or the organ dose delivered to a patient in a CT examination can be estimated, or the performances of different CT scanners can be compared.

dose-length product (DLP): Dose descriptor used as an indicator of overall exposure for a complete CT examination in order to allow comparison of performance against a reference dose value set for the purpose of promoting optimisation of patient protection.

$$DLP = \sum_i CTDI_w \cdot T \cdot N \qquad (mGy\ cm)$$

where i represents each scan sequence forming part of an examination, and $CTDI_w$ is the **weighted CTDI** for each of the N slices of thickness T (cm) in the sequence.
dose profile: Representation of the dose as a function of position along a line perpendicular to the tomographic plane.

dosimetry phantom: See **CT dosimetry phantom**.

dynamic scanning: A method of obtaining CT scans in rapid sequence so as, for example, to follow the passage of contrast material through vessels or tissue, or to decrease examination time.

effective dose: Risk-related quantity used as indicator of overall patient dose. It is defined by the International Commission on Radiological Protection (ICRP) in Publication 60 (1991) as the sum of the weighted absorbed doses in all tissues and organs of the body:

$$E = \sum_{T,R} w_R \cdot w_T \cdot D_T \qquad (mSv)$$

where D_T is the absorbed dose (mGy) in tissue T due to radiation R, w_R is the weighting factor for radiation R and w_T is the weighting factor for tissue T. For x-rays, w_R is equal to unity.

exposure factors: The settings of x-ray tube voltage (kV), tube current (mA) and **exposure time** (s).

exposure time: Duration of emission of radiation by the x-ray tube (seconds) for an individual slice in axial scanning or total acquisition time for helical scanning.

field of view (FOV): The maximum diameter of the reconstructed image.

filter: Mathematical procedure used for the **convolution** of the attenuation profiles and the consequent reconstruction of the CT-image.

focal spot: The effective area on the x-ray tube anode from which x-rays are emitted. The size of the focal spot has influence on **spatial resolution**.

full width at half maximum (FWHM): Interval parallel to the abscissa between the points on a curve with the value of one-half of the maximum of the symmetrical curve.

gantry: Scanner structure containing the x-ray tube, collimators and the **detector array**.

gantry aperture: Diameter of the physical opening of the **gantry** through which the patient is moved for the examination.

gantry tilt: The angle between the vertical plane, and the plane containing the x-ray fan beam and the **detector array**.

helical CT: A particular technique of scanning in which there is continuous rotation of the x-ray tube coupled with continuous linear translation of the patient through the **gantry aperture** in order to achieve volumetric data acquisition. Also known as **spiral** or **volume CT**.

high contrast resolution: See **spatial resolution**.

HU (hounsfield units): See **CT number**.

imaging volume: See **volume of investigation**.

intensity: The quantity of radiation energy flowing through unit area in unit time.

interpolation: A mathematical method of averaging or smoothing images that are being displayed

on a larger number of **pixels** than that for which they were originally reconstructed.

inter-slice distance: The distance between the adjacent nominal margins of consecutive slices in serial CT scanning. It is dependent upon the couch increment between slices.

linearity: In CT, the extent to which the **CT number** of a given material is exactly proportional to its density (in HU unit).

linear attenuation coefficient: The fractional reduction in intensity per unit thickness of material as an x-ray beam passes through an absorber. For a polychromatic beam, the effective linear attenuation coefficient depends on the effective energy of the beam, and the density and atomic number (composition) of the material.

kernel: See **filter**.

low contrast resolution: A measure of the ability to discriminate between structures with slightly differing attenuation properties (**CT number**). It depends on the stochastic **noise** and is usually expressed as the minimum detectable size of detail discernable in the image, for a fixed percentage difference in contrast relative to the adjacent background.

Monte Carlo Technique: A technique for obtaining an approximate solution to certain mathematical and physical problems, characteristically involving the replacement of a probability distribution by sample values, usually performed using a computer.

multiple scan average dose (MSAD): The MSAD is the average dose across the central slice from a series of N slices (each of thickness T) when there is a constant increment I between successive slices:

$$MSAD = \frac{1}{I}\int_{-\frac{I}{2}}^{+\frac{I}{2}} D_{N,I}(z)dz \qquad (mGy)$$

where $D_{N,I}(z)$ is the multiple scan dose profile along a line parallel to the axis of rotation (z).
For a sufficient number of slices such that the first and the last in the series do not contribute any significant dose over the width of the central slice:

$$MSAD = \frac{T}{I}\,CTDI \qquad (mGy)$$

noise: Noise is the point-to-point variation in image density that does not contain useful information. The magnitude of noise is indicated by the percentage standard deviation of the **CT numbers** within a **region of interest** in the image of a uniform substance (generally water), relative to the difference in CT numbers between water and air.

nominal (tomographic) slice thickness: The **slice thickness** selected and indicated at the control panel of the CT scanner.

number of measurements: The total number of attenuation values measured during the acquisition of the **raw data** for a single slice.

packing factor: In relation to dosimetry for serial CT, the packing factor (p) is used to spread the radiation density evenly over the **volume of investigation** when the slices are not contiguous. For a series of N slices, each of thickness T, and with a **couch increment** I such that the total scan length is L:

$$p = \frac{T\,N}{I\,(N-1) + T} = \frac{T\,N}{L}$$

p = 1 for contiguous slices

p > 1 for overlapping slices
p < 1 for gaps between slices.

partial volume effect: The inaccuracy in **CT number** caused by the presence of a structure within only part of a **slice**. Such effects become less important as the **slice thickness** is reduced.

pitch factor: In relation to helical CT, ratio of the patient couch travel in horizontal direction per rotation of the x-ray tube divided by the product of the number of tomographic sections produced by a single rotation of the x-ray tube N times the **nominal tomographic slice thickness** T:

$$CT\ pitch\ factor = \frac{\Delta d}{N \times T}$$

where:

Δd is the patient couch travel in horizontal direction
N is the number of tomographic sections produced by a single rotation of the x-ray tube
T is the **nominal tomographic slice thickness**.

pixel: Individual square picture element of a digital image display, being the two-dimensional representation in **HU** of a **voxel** within the scanned slice. Pixel size is determined by the diameter of the **field of view** and the number of elements in the **display matrix**.

polymethylmethacrylate (PMMA): Polymethylmethacrylate, a polymer plastic commercially available for example as Perspex or Lucite.

profile of CT numbers: Representation of the **CT numbers** of the **pixels** along a specified direction in a CT image.

quantitative computed tomography (QCT): The use of CT images and the corresponding **CT numbers** for quantitative characterization of organs or tissues. QCT is most-widely used in relation to the determination of bone mineral content and treatment planning in radiotherapy.

radiographic exposure: Product of tube current and exposure time.

raw data: The values of x-ray **detector** response from all views and **rays** within a scan. These data are convolved with the **convolution** filter and undergo **back projection** to produce a CT image.

ray: The narrow beam of x-rays from the tube **focal spot** to a single **detector** within a **detector array**, giving rise to a detector reading. Each view or projection is composed of numerous rays.

reconstruction algorithm: Mathematical procedure used to convert **raw data** into an image. Different algorithms are used to emphasize, enhance, or improve certain aspects of the data.

reconstruction matrix: The array of rows and columns of **pixels** in the reconstructed image.

region of interest (ROI): Localised part of an image defined by the operator which is of particular interest at a given time.

ring artefacts: Circular **artefacts**, usually found in third-generation scanners, caused by faulty calibration or a defect in detector function.

scanning: The process of recording x-ray attenuation data through a slice of an object, from which images are reconstructed.

scan projection radiograph (SPR): Generic name for the digital image obtained by linearly translating the patient through the **gantry aperture** during an x-ray exposure while the x-ray tube remains stationary. The SPR has a similar appearance to a plain radiograph and is used primarily for localizing the required region of scanning. Synonymous terms include radiographic mode and localizer image, together with the proprietary names Pilot scan, Scanogram, Scanoscope, Scoutview, Surview and Topogram.

scan time: The time interval between the beginning and the end of the acquisition of **attenuation** data for a single exposure. For some CT scanners, this may be longer than the **exposure time** due to the pulsing of x-ray emission.

scattered radiation: Secondary radiation belonging to the same radiation type as the original radiation, produced in the interaction of the original radiation with a material medium. The interaction can be characterized by a reduction in radiation energy and/or by a change in the direction of the radiation.

sensitivity profile: Relative response of a system for CT as a function of position along a line perpendicular to the tomographic plane.

signal to noise ratio: The ratio of the strength of the signal for information content in the image to the noise level (the standard deviation of the signal).

slice: Tomographic section (defined by position and thickness) of a **test phantom** or patient under investigation during a single CT exposure in serial scanning.

slice thickness: Effective thickness of the tomographic section, as measured by the **full width at half maximum** of the **sensitivity profile** in the centre of the scan field.

spatial resolution (or high contrast resolution): The ability to resolve different objects in the displayed CT image, when the difference in **attenuation** between the objects and the background is large compared to **noise**; normally a difference corresponding to at least one hundred **HU** is considered adequate.

spiral CT: See **helical CT**.

stability: The maintainance over time of constancy of **CT numbers** and **uniformity**.

standard examination: Outline of scanning procedure for a particular clinical indication that is generally accepted as being able to provide adequate clinical information in most of the patients examined.

test phantom: Object of particular shape, size and structure (including standardised representations of human form), used for the purposes of calibration and evaluation of performance of CT scanners.

uniformity: Consistency of the **CT numbers** in the image of a homogeneous material across the scan field.

volume CT: See **helical CT**.

volume of investigation (imaging volume): Entire volume of the region under investigation by scanning.

voxel: Elementary volume element (expressed in units of mm^3) within the scanned slice of the object, with which **CT numbers** are associated.

weighted CTDI ($CTDI_w$): An estimate of the average dose over a single slice in a **CT dosimetry**

phantom that is used to allow comparison of performance against a reference dose value set for the purpose of promoting optimisation of patient protection.

$$CTDI_w = (1/3 CTDI_{100,c} + 2/3 CTDI_{100,p}) \quad (mGy)$$

where $CTDI_{100,c \text{ or } p}$ refer to measurements of $CTDI_{100}$ at the centre (c) or periphery (p) of the head or body phantom for the settings used in clinical practice.

window level: The central value of the window (in **HU**) used for the display of the reconstructed image on the image monitor of the CT scanner.

window setting: The setting of the **window level** and the **window width**, selected for optimization of the grey scale levels in the displayed CT-image.

window width: The range of **CT numbers** within which the entire grey scale is displayed on the image monitor of the CT scanner.