Clinical and associated performance parameters for MSCT

A series of clinical factors play an important part in optimising CT so that examination is effective and radiation dose is limited to the minimum necessary. They are important in ensuring that diagnostic quality is provided with a reasonable radiation dose to the patient, i.e. the process of **optimisation** is observed.

The decision to submit a patient to CT occurs only after **justification** of the referral. The examination should only be carried out on the basis of a justifiable clinical indication and the referring clinician is required to give adequate and accurate clinical information to the radiologist so that an informed decision on justification can be made.

The radiologist approving referrals for CT must have access to the records of previous imaging investigation so that examinations are not repeated unjustifiably. Such information may also be used to limit the extent of the CT examination when previous investigations have provided some of the information required.

An essential step in justification is to consider whether the clinical indication might be satisfied by investigations that do not require ionising radiation, notably ultrasonography (US) or magnetic resonance imaging (MRI). These investigations should be carried out if they would satisfy the clinical referral, or if they might provide sufficient information to prevent a significant number of patients proceeding to CT. They are also recommended when CT is unadvisable because of contrast medium hypersensitivity or nephrotoxicity.

In certain applications, prior investigation (imaging or otherwise) may be required in order to optimise CT.

SUPERVISION

CT should be performed under the clinical responsibility of a radiologist. Recommended examination protocols for standard patients should be available.

Radiation dose constraint is aided by terminating the examination when the clinical requirement has been satisfied. Termination is also required when problems occurring during the examination (for example unexpected lack of cooperation by the patient or the discovery of contrast media residue from previous examinations) cannot be overcome. This is not always possible in MSCT since the data are often acquired in one exposure. Careful review of previous imaging and clinical records is mandatory to avoid unsuccessful examinations whenever possible.

Radiologists and radiographers **must** be aware of clinical or technical problems which may interfere with image quality. Many of these are particular to specific organs and tissues and

may lead to modification of technique. Radiologists and radiographers must be also aware of manoeuvres to overcome such problems.

PATIENT PREPARATION

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

Cooperation. Patient cooperation should be ensured as far as possible. An explanation of the procedure should be given to each patient and appropriate consent obtained. Good communication with and control of the patient is desirable throughout the whole examination.

Protective shielding. Relevant protection for sensitive organs close to the target volume is a lead-purse for the male gonads if the edge of the exposure beam is less than 10 to 15cm away from the testicles. Appropriate protection measures must be applied to persons who need to accompany patients into the examination room during the examination.

Clothing. The area of examination should be free of metal or other radio-dense items where possible. Special attention must be given to eliminating such materials in the patient's clothes or hair.

Previous contrast media studies. CT examinations may be rendered unsuccessful due to artefact from previous contrast media studies, notably barium studies of the intestinal tract. When this cannot be avoided by prior clinical enquiry, careful inspection of the scan projection radiograph should be made to determine whether proceeding with CT is justified.

Fasting. Fasting prior to the examination is not essential. Restraint from food for three hours (but not fluid) is recommended if intravenous contrast media are to be administered.

Contrast media. CT examinations of the abdomen and pelvis frequently require contrast media to be administered by mouth. In selected examinations intracavitatory injection of contrast media may be required. These must be administered at times and in doses appropriate to the indication. Administration of contrast medium by the rectum may be required in some examinations of the pelvis and a vaginal tampon may be used for gynaecological applications. The use of intravascular contrast media in MSCT is considered below.

Positioning and motion. Most CT examinations are carried out with the patient supine; the patient is most comfortable with the knees flexed. Alternative positioning may be required to aid comfort and cooperation, for appropriate display of lesions, to reduce absorbed radiation dose to particular organs, or to minimise artefact. Motion should be kept to a minimum to

reduce artefact: typical sources of artefact are involuntary patient movement, respiration, cardiovascular action, peristalsis and swallowing.

It was previously necessary when using incremental CT for specialised examinations to acquire images in planes other than the axial plane. MSCT has largely removed the requirement for non-axial acquisition since the quality of multiplanar reformatting is superior in MSCT. However non-axial acquisition may still be required in selected cases to deliver optimal spatial resolution in the desired plane or avoid direct radiation of sensitive organs such as the female gonads and the eye lenses.

EXAMINATION TECHNIQUE

In MSCT the relationship between examination and exposure parameters is more complex than in incremental CT. In practice for most examinations, one parameter is defined as being dominant by the clinical indication and other parameters are adjusted accordingly.

The advice given below refers to the use of CT systems in helical mode. It should be remembered that in selected circumstances these systems are also used in incremental mode, with the advantage of the capability to acquire several sections in one exposure.

Scan projection radiograph

A **scan projection radiograph** (SPR) 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 the SPR provides only a small fraction of the total patient dose during a complete CT procedure.

Acquisition time

The acquisition time (scan time) is the duration of x-ray exposure required to generate one set of data (one sequence). It is dependent on the target volume, table speed and the speed of rotation of the tube.

The **target volume** or imaging volume is the whole volume of the region under examination. It is defined by the outermost margins of the examination in the longitudinal axis and the cross-sectional area of the exposure. It must include all the tissues relevant to the clinical indication.

The **table speed**, usually measured in cm per second, determines the time in which the target volume is covered in one exposure.

The **rotation time** determines the speed at which the tube rotates around the patient. In conjunction with table speed it defines the length of table movement for each rotation of the x-ray tube.

Acquisition time is a critical factor in planning examinations which need to be completed quickly, for example in patients who have difficulty cooperating or controlling involuntary movement. This is facilitated by limiting the target volume whenever possible. When this is not possible other parameters have to be adjusted to compensate for effects on pitch and beam collimation. Acquisition time may also be a critical factor in appropriately timing exposure in examinations using multiphase enhancement, as described below.

Exposure factors

Exposure factors are those scanner settings that influence data acquisition. MSCT shares with incremental CT the exposure factors of **beam collimation, x-ray tube voltage (kVp) and tube current (mA)**. In helical and MSCT, the **acquisition time** defines the exposure time for one target volume and there is also the further factor of **pitch**.

In general, **tube voltage** is limited to a choice of discrete values, usually between 80 and 140 kVp. High tube voltage is recommended for imaging large body parts that show high attenuation of x-rays, e.g. the pelvis, or obese patients. . Soft tissue structures are usually best visualised using the standard tube voltage for the given equipment.

MSCT allows a greater choice of tube voltage than incremental CT. There has been a recent trend to employ lower tube voltages in order to improve contrast resolution in images. This approach requires an increase in exposure to compensate for higher noise levels. The approach is justified only when the resulting dose is lower than that which would have been administered using standard tube voltage.

At given values of tube voltage and section thickness, the image quality depends on the product of the **acquisition time** and the **tube current** (mA), and on the **pitch**. Absolute values of mAs depend on the type of scanner and the patient size and composition. For a particular CT model, an increase in radiographic exposure (mAs) is accompanied by a proportional increase in absorbed dose. Higher values of radiographic exposure should therefore be used only in cases where a high signal to noise ratio and optimal contrast resolution are indispensable.

In MSCT narrower beam collimation permits greater z axis resolution in the volumetric data, independent of the slice thickness of the reconstructed viewing image. In MSCT, however, the image quality contained in the target volume also depends upon the **pitch** in use, which in turn imposes limitations on **table speed** and **acquisition time**.

The **pitch** of the exposure defines the path that the helical exposure makes through the patient. It is generally defined as the table travel for one rotation, divided by the width of the detector configuration. Some manufacturers have chosen to express pitch as the table travel divided by the width of the individual detector arrays in use, irrespective of their number. Some manufacturers optimise their CT equipment to a limited number of pitch options. If other factors are constant, absorbed dose decreases with increasing pitch, especially when the pitch exceeds 1 and there is no overlap of the exposed regions within the helix.

A degree of overlap improves the quality of data in the target volume and at constant radiographic exposure reduces noise in the reconstructed section and improves contrast resolution. However it also increases exposure and should therefore Preferably be performed at reduced radiographic exposure.
Among the dose constraint options available in CT is reduction of exposure when carrying out examinations for the purpose of monitoring disease which has been adequately demonstrated previously. In such examinations dose constraint is served by reducing the exposure parameters or limiting target volume.

Image reconstruction

MSCT permits the production from one target volume of section of different thickness, characteristics and plane. This process is limited to the extent that the beam collimation and size of detectors generally define the maximum resolution available in the z axis, and therefore the thinnest image sections that can be reconstructed.

The primary section reconstruction will usually be in the axial plane and will generally consist of the thinnest section and greatest resolution available. These sections may not be used for primary interpretation but should be archived and available for review.

Section thickness defines the dimensions in the z axis of the reconstructed image, combining with the pixel size to define voxel size. As in incremental CT, the larger the thickness of the reconstructed section, the greater the low contrast resolution in the image; the smaller the slice thickness, the greater the spatial resolution. If the section thickness is large the images can be affected by artefact due to partial volume effect within the section; if the slice thickness is small (e.g. 1mm) the sections may be significantly affected by noise. Selective image reconstruction from the target volume may be used to create separate sets of viewed images of differing thickness, thereby exploiting both forms of resolution.

Thicker images may be reconstructed for viewing if low noise and good contrast resolution are required. The maximum image quality is dependant on the exposure level, so that thick sections reconstructed from data acquired at high pitch or low tube current cannot achieve the contrast resolution levels possible when using low pitch or high tube current. The choice in

practice is dictated by the dominant image characteristic required for the examination, with due regard to the radiation dose.

Unlike incremental CT MSCT offers no dose-sparing advantage of **spacing** of viewed sections and using an interval or gap is not usually a desirable feature of image construction in MSCT. Viewed sections may be contiguous or reconstructed with a degree of **overlap**, to avoid partial volume effect or the exclusion of small lesions . The drawbacks to this approach are an increase in the number of images to be viewed and also data archive space if all images are to be stored.

As the thickness of reconstructed sections decreases, overlap becomes less important for confidence in interpretation. However a degree of overlap may still be desirable to improve the quality of multiplanar or 3D reconstructions.

The **field of view** (FOV) is the maximum diameter of the reconstructed image. Its value is selected by the operator and generally lies in the range between 12 and 50cm. A small FOV provides increased spatial resolution because the whole reconstruction matrix is used for a small region. This results in reduction of the pixel size. Selection of the FOV must take into account not only the opportunity for increasing spatial resolution but also the need to demonstrate all areas of possible disease. If the FOV is too small relevant areas may be excluded from the image.

Reconstruction matrix is the array of rows and columns of pixels in the reconstructed image, typically 512 x 512. Together with the FOV the matrix defines pixel size (voxel diameter).

The **reconstruction algorithm** (filter or kernel) is defined as the mathematical procedure used for the convolution of the attenuation profiles and reconstruction of the CT image. In most systems a range of reconstruction algorithms is available. Appearances and characteristics of the image depend strongly on the algorithm. Many systems have dedicated algorithms for selected examination areas. Depending on clinical requirement, it may be necessary to select a high resolution algorithm, providing greater spatial resolution for detailed representation of bone and other regions of high natural contrast such as pulmonary parenchyma.

The use of intravascular contrast media

Intravascular contrast media are widely used in CT to improve contrast in tissues (**enhancement**), or to facilitate characterisation of lesions. The increased flexibility of MSCT has extended the applications of enhancement. In particular, MSCT allows entire organs to be examined with precise exposure timing relative to the phase of perfusion.

Contrast medium administration constitutes additional risk and invasion for the patient. It should only be used when justified by the clinical indication. The recent trend in CT practice is to use enhancement routinely for many indications in order to improve image contrast. This approach must be justified by increased diagnostic sensitivity and may then assist in dose constraint by utilising the improved image quality to allow a reduction in exposure.

Ultrasonography and MRI are preferred investigations when contrast media are believed to impose increased patient risk, for example in contrast medium hypersensitivity.

The route of administration is generally through a peripheral vein and media may be given by infusion, hand injection or using a pressure injector, depending on the desired bolus profile.

The **dose** and **concentration** of contrast media should be appropriate to the clinical indication and should provide a level of enhancement which is adequate for interpretation. The use of inadequate doses of contrast media must be avoided since an unsuccessful examination may result in repeat exposures.

The **flow rate** and method of injection determines the bolus profile during the first circulation and are dependent upon the clinical indication. Where exposure is to be timed to the first or early circulations it is recommended that a pressure injector be used to give optimal bolus profile and accurate timing. The intravascular access catheter should be of appropriate diameter to allow the required flow rate.

The **delay** between injection and timing of x-ray exposure relative to the circulation time determines the **phase of perfusion** which is demonstrated by the acquisition. The first circulation demonstrates arterial supply at optimal enhancement; further circulations produce mixing in the vascular compartment and tissues are enhanced due to the presence of contrast medium in the extracellular space. Later exposure may be utilised to demonstrates venous phase. The need for optimal bolus profile and accurate timing of exposure decreases with increasing delay from injection.

Many systems now permit automated bolus tracking, using a low x-ray exposure at a selected site to detect the arrival of a test dose of contrast medium, thereby providing automated control of appropriate exposure delay.

An advantage of good bolus profile and accurate exposure timing is that in selected circumstances the dose of contrast medium may be limited to the minimum necessary to demonstrate the required phase of enhancement.

MSCT allows organs to be examined rapidly in a single breath-hold and allows an examination to include multiple phases of enhancement following a single injection (**multiphase studies**). This approach increases x-ray exposure in proportion to the number of

phases and must be justified by increased diagnostic sensitivity. The target volume and number of phases must therefore be defined in relation to the clinical indication. The use of multiphase study as a routine approach cannot be supported.

The **timing** of phases depends upon the clinical indication and whether arterial, capillary or venous phases are required. It is particularly important in multiphase studies that timing of exposure is accurate, so as to avoid unjustifiable patient exposure

In multiphase studies the **target volume** should be limited to the precise area under clinical investigation, so as to reduce repeated exposure to surrounding tissues.

Reformats

With the possibility to obtain nearly isotropic voxels with MSCT, CT transforms from a transaxial into a truly tree-dimensional imaging technique where reformatted slices can have a high diagnostic quality. The type of appropriate reformats and their orientation depends on the anatomical area and the diagnostic problem.

Multiplanar reformats (MPR) are two-dimensional reformatted slices that can be reconstructed in arbitrary planes from the axial CT sections. MPR can assist the diagnosis by providing further information in the axial plane as well as in other viewing planes.

The **plane orientation** of MPR is variable. Axial MPR comprising slices thicker than the primary axial CT sections is often necessary to keep image noise low. The same apply to MPR in other planes, which especially is important in areas with partial volume effect due to the axial slice orientation being parallel or oblique to the tissue boundaries such as the diaphragm and apex of the lung. Standard straight reconstruction in the coronal and/or sagittal plane is recommended to familiarize the radiologists and the clinicians with the views. However, curved MPR may be valuable for imaging vessels.

The **thickness and spacing** of MPR should be chosen according to the diagnostic problem. Thick MPR can provide an overview of anatomy and pathology based on a reduced number of slices, which also aid image transfer or filming. Spacing of MPR sections may further reduce the number of images, but with the risk that image information may be missing.

3D reconstructions based on MSCT can be of high quality, and include many possibilities such as shaded surface display (SSD), **Maximum or minimal intensity projection (**MIP/MinIP), Volume rendering (VR) and virtual endoscopy.

Shaded surface display (SSD) or 3D surface rendering provide a three-dimensional view of the surface of a structure of interest in the acquired volume data set for example the bony pelvis or abdominal aorta. Segmentation of the object concerned from the background may be necessary before SSD is performed if the object cannot be defined by selecting a suitable range of CT numbers. SSD is especially valuable with regard to bone fracture and dislocation.

Maximum intensity projection (MIP) is generated by projecting the actual slices of a volume in a viewing plane and display the maximum CT numbers. Alternatively the

minimum CT numbers are displayed (**minimal intensity projection (MinIP***))*. MIP may be valuable for imaging vessels (CT angiography) and specialised pulmonary conditions, whereas MinIP is useful mainly for visualizing the central tracheobroncheal system.
Volume rendering (VR)*,* which is generated by casting rays through the volume of interest according to preset rules, has combined characteristics of SSD and MIP. VR technique (VRT) can either create a transmission display (similar to MIP) or a surface display (similar to SSD) depending on the amount of gradient shading. VR may be valuable for imaging vessels (CT angiography), skeletal structures, the tracheobroncheal system and lungs (virtual bronchoscopy), and the colon (virtual colonoscopy).
Virtual endoscopy is a 3D rendering technique that simulates endoscopic views e.g. bronchoscopy, laryngoscopy, colonoscopy and angioscopy.

Dose implications of reformats

Reformats are made based on the primary axial sections and therefore usually do not cause extra exposure, but it is often necessary for sections to be reconstructed with overlap to obtain good reformats. This does not imply scanning with overlap as axial slices can be produced at arbitrary levels, overlapped if desired, without having overlap during acquisition (pitch ≥1). Overlapping acquired sections may only offer slight advantages for SSD reconstruction of contours that are parallel to the scan plane (e.g. the calvaria).

Image viewing conditions

One of the great challenges of MSCT is to deal with the large number of sections and data load. It is necessary to change the way in which radiologists interpret the images and how the CT data are transferred and stored. Film documentation of all sections is no longer an option. Instead workstation-based review of axial slices and multiplanare reconstruction for interpretation is necessary. In addition alternative visualization and analysis using volumetric tools such as MIP, SSD and VR should be implemented in daily practice. With all the options for reconstruction the diagnostic workstation should be dedicated and allowing the performance of reconstructions. If the number of sections is large, it may be beneficial to view them in an interactive cine display, which provides a three-dimensional impression of complex non-linear structures that have multiple intersections with the image plane. Viewing on less advanced consoles may be restricted to fewer images in the form of thicker combined slices.
Viewing images on consoles or workstations requires viewing monitors with brightness and contrast set to give a uniform progression of the grey scale from black to white, and the screen quality should be maintained through regular control. The display matrix should be at least 1024 x 1024.
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.

Film processing

As a rule, all acquired images cannot be documented on film. If it is necessary to document on film this can be done by printing every second or fourth primary section, depending on the type of examination, or better combine thicker slices with less noise, which are particular beneficial for sections taken with at low dose or a thin collimation.
It is important for the diagnostic image quality that the film processing is optimal. Therefore film processors should be maintained at their optimum operating conditions as determined by the manufacturer, including regular quality control.

Documentation (archiving)

A marked disadvantage of multislice CT is the increased data load. A CT of the chest and abdomen may produce 500-800 sections depending on the degree of reconstruction overlap. The only way to avoid this enormous amount of data is to acquire and reconstruct thicker slices, but many of the advantages of multislice CT will thereby be lost.
Digital archiving of the primary sections is recommended. It is then always possible to make adequate secondary reconstructions. However, for distribution of images to clinical departments it is usually necessary to reduce the number by making representative thicker combined (stacked) slices. This increases the demand of digital digital data space if the primary slices also are archived.
When **film documentation** is used, the films should be store in accordance with the national laws.

Archiving of reformats and measurements

It is essential to have adequate documentation of suspicious or abnormal findings. All reformats, slices and measurements, which have contributed to the diagnosis should therefore be archived, especially if the primary slices are not preserved digitally.

5. Clinical and performance parameters: MSCT in paediatric patients

Indication

The appropriateselection of paediatric patients who need MSCT is the first important step, because alternative cross sectional imaging techniques, such as ultrasound and MRI, are often sufficient to make the diagnosis without radiation exposure. In order to make intelligent use of the potential of MDCT, i.e. to determine the optimal scan techniques and reconstruction parameters, it is necessary to define clearly the diagnostic questions for the CT examination. In addition, it is still advisable in the individual patient to perform preliminary simple examinations, i.e. an actual chest radiographor ultrasound. Thereby, the CT can be modified or even cancelled in some patients. In other cases, especially when the chest radiograph is inconclusive, an echocardiography can completely change the MSCT-protocol, for example. incongenital heart diseaseassociated tracheo-bronchial and vascular anomalies frequently occur. It is then necessary to investigate the chest and the upper abdomen (whole liver) to delineate the vessels, which can cross the diaphragm, (sequestration complex), and the rare cases of anomalous pulmonary vein connections and portal vein absence etc.. In addition, tracheal and bronchial pathology can be concurrently viewed, using MPR and 3- D reconstruction to show the exact anatomical relations.

Patient preparation

Of utmost importance is appropriate patient preparation, may be essential to have a large intravenous line in infants and small children to administer contrast media (CM) at a high flow rate. Secondly, for abdominal CT, adequate bowel opacification is obligatorybut difficult to achieve in young patients. Sometimes oral CM can only be applied in paediatric patients by a nasogastric tube; the administration time is shorter because peristalsis is faster than in adults. Attention should be given to simple, often forgotten metal items; e.g. metallic buttons in baby clothes, metallic wires of medical monitoring devices and electrodes or other cables. These can cause massive artefactand should be removed before scanning. Correct positioning is important, but this can sometimes be a difficult task in patients with severe scoliosis.

Higher Speed

This is a very important feature of MSCT, especially using 16 row detectors, compared to single slice scanners. Spatial resolution in the xandy-planes is better because slice thickness is much smaller. Another important aspect is rotation time, which is twice as fast compared with single detector scanners. Faster tube rotation is important avoiding blurring of moving structures, for example when examining small pulmonary structures (bronchi, vessels, septa) which are in close contact to the beating heart or diaphragm. This is most advantageous for the smaller patient, because their heart rate and respiratory movement are much faster than in

more cooperative older children (after the age of eight), who can generally hold their breath. The better resolution in the z-axis is independent of age. However, nurses and anaesthesiologist who care for the small patient must take the faster table movement into account.

MSCT not only has the potential for better spatial and contrast resolution but also allows reduction of tube current and tube voltage in young patients. In the future, automatic modulation of the tube current will become possible and should be used not only to keep the image quality high (noise reduction), but should allow, dependent of the patient thickness, dose or noise- reduced protocols, respectively. However, tube current can be calculated after the scan projection radiograph is obtained by measuring the patient's thickness (absorption) and thereby correctly changed before CT scanning. Thereby, dose optimised paediatric protocols can be achieved. This is important for high resolution CT (HRCT), which is being more frequently requested. In contrast to adults, optimal HRCT in children is difficult to performe, because breath holding is needed to avoid misinterpretation of motion artefacts as pathologic findings. Therefore, more research is necessary to define optimal scan techniques, especially for paediatric chest CT examinations.

Contrast medium

The amount and the speed of intravenous contrast medium administration have to be based on patient's weight and the type of the examination.

More contrast medium is needed in trauma patients or when trunk CT angiography is necessary. Only low osmolar CM should be given to a paediatric patient. Faster table movement (less administration time) must be taken in to account when intravenous contrast is applied in paediatric patients. Therefore, the correct delay in different age groups must be exactly defined and bolus tracking technique should be preferably used despite the extra dose it requires. Only very rarely is multiple scanning indicated in paediatric patients. Probably the only indication for multiple scanning is in selected cases of complex liver lesions.

Outlook

Despite unavoidable radiation exposure, the benefit of optimal MSCT in paediatric patients is very high. Exact knowledge of pathology of critically ill patients allows earlier diagnosis, more specific treatment and, therefore, better clinical outcome. The main indications for MSCT in paediatrics in the future will be severe trauma, complex malformation syndromes and rare pulmonary diseases.