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Guidelines for paediatric CT examinations

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Several paediatric radiologists and medical physics experts who are specialized in paediatric CT imaging and also scanner suppliers have taken part in preparing this guide. STUK expresses its greatest thanks to them for sharing their expertise and their good cooperation.

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1. Introduction

The Radiation and Nuclear Safety Authority (STUK) has previously published two guidebooks in 2005 and 2008 giving guidance for paediatric x-ray procedures, including indications, guidelines for selecting imaging parameters, optimization and proper use of radiation shields. Although both of the previous guides briefly discussed also computer tomography (CT) examinations, this guide reviews more closely and accurately the guidelines and taking into account the development of CT technology and the changed scanning routines. There is also a separate guide for determining patient doses in x-ray procedures published in 2004 that gives guidelines for dose measurements of CT examinations and determines the dose quantities more closely.

This new guide gives the basics of optimizing CT examinations and some technical features of the CT scanners of the four most common CT manufacturers in Finland. Justifying and optimizing CT examinations (indications, performing the examination) are discussed covering each anatomical area, and separately for trauma and orthopaedic examinations. In addition, guidelines for CT examinations in nuclear medicine (the so called hybrid imaging) are given.

2. General information

Children are of special concern in radiation protection because radiation exposure during childhood causes larger additional cancer risk than a corresponding exposure in adulthood. Therefore justification and optimization of paediatric examinations needs special attention. Although we try to avoid imaging techniques that use ionizing radiation in paediatric examinations, CT is still needed in paediatric imaging.

A paediatric CT examination should always be planned individually for each child. Routine examination practices without individual consideration should be avoided, and only the series essential for diagnosis should be done. Fast multi-slice scanners have reduced the need for sedation, and most examinations can be performed even without a breath hold. The requirements for a successful examination include: professional performance, carefully planned working phases and advising the child, parents and other assisting persons in a peaceful atmosphere.

Criteria for a good CT examination include

- adequately versatile, case-specifically tailored imaging practises
- minimizing the length of the scan range according to the indications and anamnesis received
- acceptable image quality, being assessed case-specifically by the responsible radiologist (e.g. noise level and slice thickness used on viewing) so that the patient's radiation exposure is kept as low as possible.

Guidance for using radiation shielding is given in item 3.3.

3. Basics of optimizing CT examinations

Children are smaller than adults and thus the attenuating tissue layer is also smaller, so the radiation scatters and attenuates less when going through a child than when going through an adult. Thus lower dose levels may give sufficient image quality.

3.1 Scanning parameters

Scanning parameters affect the patient's radiation exposure but also the scan range and the patient's size affect patient's individual dose distribution and the organs exposed to radiation. Since the dose display values of a CT scanner don't consider the individual patient features, the dose display values can't be directly used to assess the patient's individual radiation risk resulting from a CT scan, especially in the case of children.

Scanning voltage and tube current

A patient's radiation dose is directly proportional to the **tube loading** (mAs, the product of the tube current and scanning time) of the x-ray tube. On the other hand, image graininess (noise) is inversely proportional to the square root of radiation dose. Thus the effect of changing the mAs on patient dose and image noise can be predicted by calculations. The tube voltage affects both the dose and image quality in a more complicated way.

> A patient's radiation dose is directly proportional to the tube loading (mAs). If the mAs value is doubled, dose will also be doubled.

A lower **tube voltage** (80–100 kV) can be used for optimization, especially in paediatric and contrast imaging. With a lower tube voltage the image contrast will improve and the dose will reduce as much as tens of percents. At the same time the image noise will increase, but the increased contrast will compensate for the increased noise, and thus the net effect to image quality is often positive. It may take a while for a radiologist to get used to the changed image contrast.

Planning image

The scan range is selected from the planning image (scout image or topogram). The planning image should be long enough to cover the whole area of interest, but unnecessary long scan ranges should be avoided. The automatic exposure control (AEC) generally uses the attenuation information obtained from the planning image to estimate the tube current needed in different parts of the patient (z direction). It is important not to have any extra attenuating material e.g. radiation shields, on the selected scan area. The tube voltage should normally be the same as for the actual scanning so that the AEC works properly.

Beam width and slice thickness

The nominal beam width in the direction of the patient's long axis (z direction) determines the length of the simultaneously scanned volume. Using beam collimators the beam width is mechanically limited as desired. *The nominal slice thickness* (collimated slice thickness) can be selected from the technical selections (e.g. 0.625 mm). The nominal slice thickness is connected to the size of the detector elements. Nominal beam width is the nominal slice thickness multiplied by the number of the slices (e.g. 64 · 0.625 mm = 40 mm).

The reconstructed slice thickness is the slice thickness of the viewed slices created from the raw data and it can't be smaller than the nominal slice thickness used for data acquisition (the size of the detector elements used). The thinner the slices one wants to view, the higher radiation dose is needed to obtain the desired image quality level (contrast-to-noise ratio). The smaller the object one wants to view, the thinner reconstructed slice thickness is needed. Usually the reconstructed slice thickness is chosen according to the indication and the child's size, e.g. for small children 2–3 mm and for larger 4–5 mm and for example in angiographies even 1–2 mm may be needed.

Nominal slice thickness = slice thickness used in scanning Reconstructed slice thickness = slice thickness used in viewing

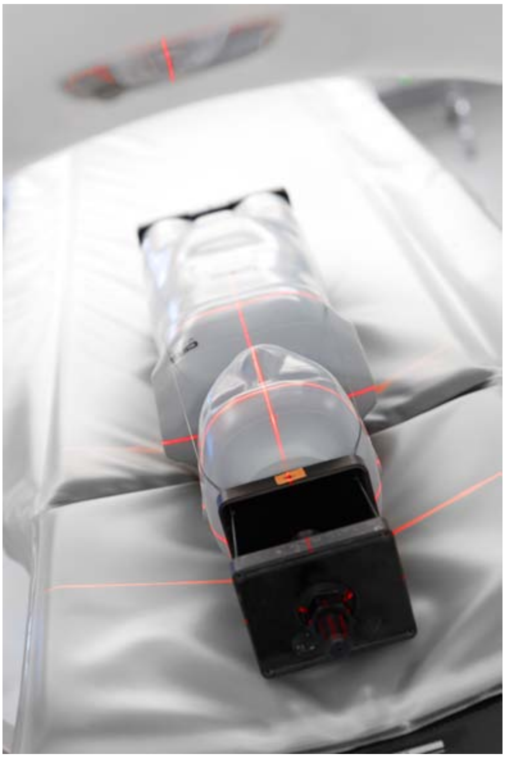
In helical scanning some extra image data is collected at the beginning and at the end of the scan range for image reconstruction, so the radiation exposure also expands outside the defined scan range (the so called overranging effect). Proportion of the overranging is relatively larger with short scan ranges, and can be up to 20% of the total dose. Therefore, in short helical series using a narrower part of the detector can be considered (so giving a smaller nominal beam width), thus the overranging will be smaller. However, only about 10% dose reduction can be achived and the scan time will increase respectively; reducing the beam width to half doubles the scan time. In some of the new scanners the helical overranging has been blocked with a special adaptive collimation. This should be verified by the scanner supplier or a medical physics expert.

The size of the scanned and displayed field of view, SFOV and DFOV

The beam size in the scanning plane (axial plane parallel to the patient's long axis**,** xy-plane) can be altered with most of the scanners by choosing the *scan field of view* (SFOV), e.g. head or body. For children a smaller SFOV should be used if possible due to their smaller size. The patient contours should fit inside the SFOV so that the partial volume artefacts can be avoided.

The size of the display field of view (DFOV) defines the objects visible in the reconstructed images and the final spatial resolution of the image in the axial plane. The axial CT image consists typically of image matrix of 512 x 512 pixels. The pixels size defines the visibility of small details, and it gets larger as DFOV is expanded. Accordingly, with a smaller DFOV the pixel size is reduced and thus spatial resolution gets better but at the same time the noise level increases. DFOV cannot be larger than SFOV.

CT scanners usually have one or more bowtie filters (beam shaping filters) that affect both the image quality and dose distribution in the axial plane. They maintain the high radiation intensity in the thickest and most attenuating part, in the middle of the patient, and lower radiation intensity on the surface of the patient. Thus a bowtie filter evens the dose and noise distribution in the axial plane, if the patient is centered properly. Centering the patient carefully to the isocenter assures the proper performance of the bowtie filters. The shape of the bowtie filter is defined according to the selected SFOV in the scanning program (if different filters are available).



Automatic exposure control (AEC)

Automatic exposure control (mA modulation, AEC) compensates for beam attenuation at different parts of the patient by changing the tube current in order to maintain constant image quality over the whole scan range. The tube current can be changed both while the tube is rotating around the patient and as the table moves in the direction of patient's long axis (z-modulation). The AEC software predicts the patient's attenuation either beforehand from the planning images or real time during the scan, or both.

However, maintaining the same image quality is not always reasonable. For example, if there is more attenuating tissue at the end of the scan range, AEC tends to increase the tube current on that area, even if a noisier image would be adequate for a diagnosis, such as evaluating lung tissue at the liver level. Setting the maximum tube current value for modulation can reduce the patient's radiation exposure without compromising image quality.

With real time tube current modulation the possible contrast media in the scanned tissues increases the current and radiation exposure of the patient. Also the use of bismuth shields on the scanned area can mislead the AEC correspondingly.

AEC is recommended for paediatric body examinations; however it's very important to know how the AEC of the particular scanner in question works.

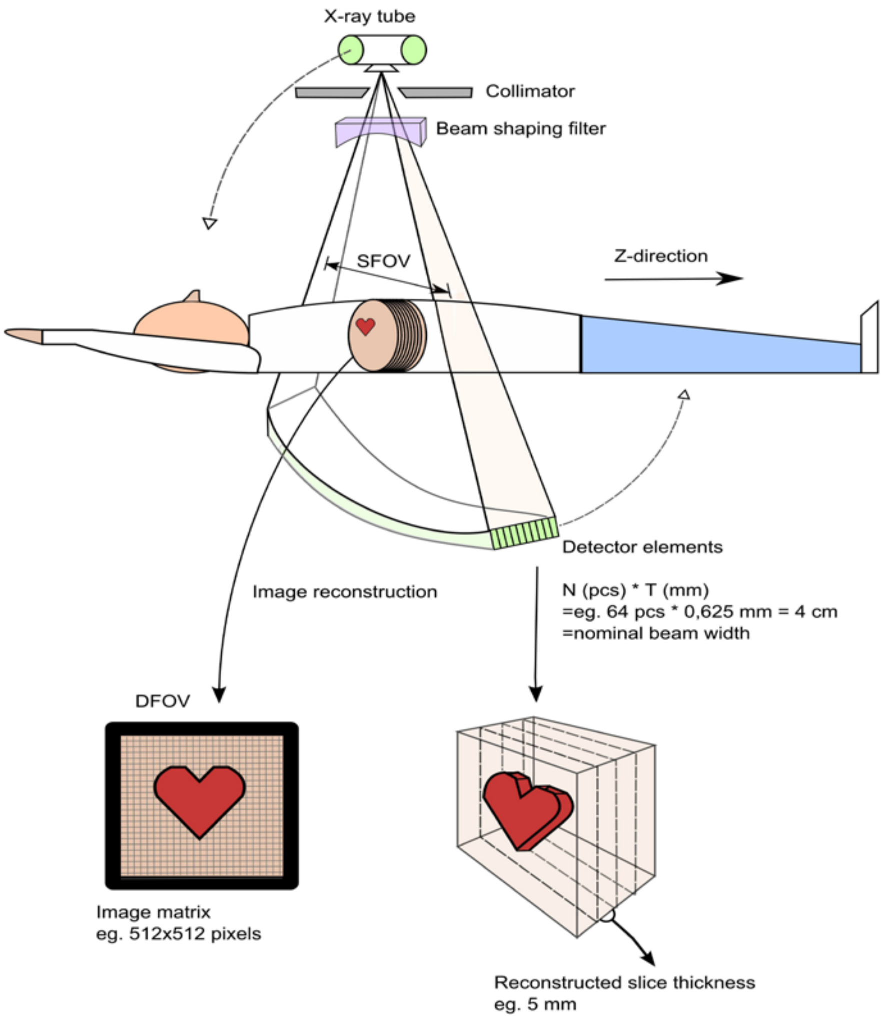


Figure 1. Steps of image reconstruction.

The image shows the steps of the CT image formation. The patient's central axis direction is called the z direction, and the x-y-plane is called the axial plane. SFOV (scan field of view) indicates the x-ray beam size in the x-y-plane. DFOV defines the field of view of the displayed images, and image matrix defines the pixel count in DFOV. The beam size in the direction of the patient's long axis, i.e. the nominal beam width, is the nominal size of the detector elements used in scanning multiplied by their number. From the "raw data" collected during scanning, displayed slices are created with different calculation processes at the workstation. The thickness of the viewed slices, i.e. the reconstructed slice thickness, can be selected as needed.

Pitch

Pitch is the shift of the scanner table during one rotation of the x-ray tube divided by the nominal beam width. With older scanners the speed of the scanner table shift may be described by the factor table feed (mm) per one rotation of the x-ray tube instead of pitch factor. Pitch can be calculated by dividing the table feed with the nominal beam width.

When using AEC, the tube current is typically automatically reduced when pitch is reduced and thus the patient dose and image noise does not change. Accordingly, the tube current will increase automatically if the pitch value is raised. With AEC, the pitch value can usually only affect the scan speed. If AEC is not used, one can make the scan faster and reduce the patient dose by increasing pitch.

With AEC it is reasonable to use pitch 1. For larger children it is possible to use pitch value higher than 1, to make the scan faster and potentially reduce movement artefacts.

If a low enough dose level cannot be achieved with AEC, dose level can be reduced by using the lowest possible fixed mA, a short rotation time and high pitch. This approach might be needed with small patients and when scanning extremities.

If the scanner automatically adjusts the current used while the pitch-factor is changing, also the tube loading (mAs) used in scanning will be changed. Some scanners indicate the tube loading using the effective mAs value (Eff.mAs) that is maintained constant against the pitch value.

$$\text{Effective mAs} = \frac{\text{Tube loading}\left[\text{mAs}\right]}{\text{pitch}} \qquad (1)$$

3.2 Dose and image quality

CT dose distribution in patient differs from the (projection-) x-ray imaging. Inner organs typically receive a relatively higher dose in CT than in a conventional x-ray image. This is why one should pay attention to the special features of CT scanning while optimizing the scan.

Technical image quality

Technical image quality is numerically indicated (and so quantifiable) and should be measured as objectively as possible. It is most simply described with noise and contrast. The contrast-to-noise ratio is obtained by dividing the difference of the CT numbers (e.g. test object's CT number compared to background in phantom) of the regions of interest (ROI) by the standard deviation (SD) of the CT numbers. The SD of the CT numbers on a uniform ROI numerically describes image noise. These quantitative image quality parameters are typically measured from a specific test phantom or visually evaluated from details of the test phantom. The technical features and scanning parameters of the scanner affect the technical image quality.

Technical image quality parameters can be used in evaluating the clinical image quality. The clinical sufficiency of the image quality should always be evaluated by a radiologist.

Noise affects clinical image quality most when low contrast resolution is important e.g. for the abdomen. In bone and lung areas, image noise is not as critical because these objects have high contrast compared to surrounding tissues. Often bones and lung can be scanned with low dose.

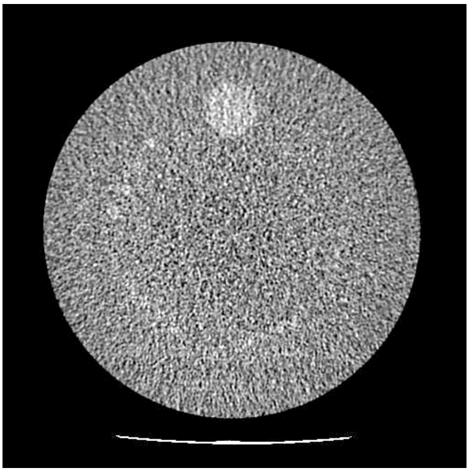


Figure 2.
Example of a test phantom that can be used for assessing low contrast test objects (lighter circles in the image).

Other technical image quality parameters typically assessed from CT images include accuracy of CT numbers (HU-units), image uniformity and resolution of small high contrast details. High noise level appears as graininess in the image. Low dose level results in a high noise level in the image, and makes it harder to see image details behind the noise.

Image noise is inversely proportional to the square root of dose, i.e. the noise will be reduced by a factor 0.7 if the dose level is doubled.

Dose quantities

The CT dose volume index $CTDI_{vol}$ describes the average radiation dose on the scanned area, measured in a standard test phantom. This test phantom is an acrylic cylinder with the diameter of 16 cm (head) or 32 cm (body). The weighted dose length product DLP_w, is the product of $CTDI_{vol}$ and the length of the scanned area d. In the dose displays of the newest scanners both $CTDI_{vol}$ and DLP_w are usually given. The accuracy of the dose display reading is verified by regular measurements, as part of the quality assurance of the scanners.

$$DLP_w = CTDI_{vol} \cdot d \quad \text{or} \quad CTDI_{vol} = \frac{DLP_w}{d} \qquad (2)$$

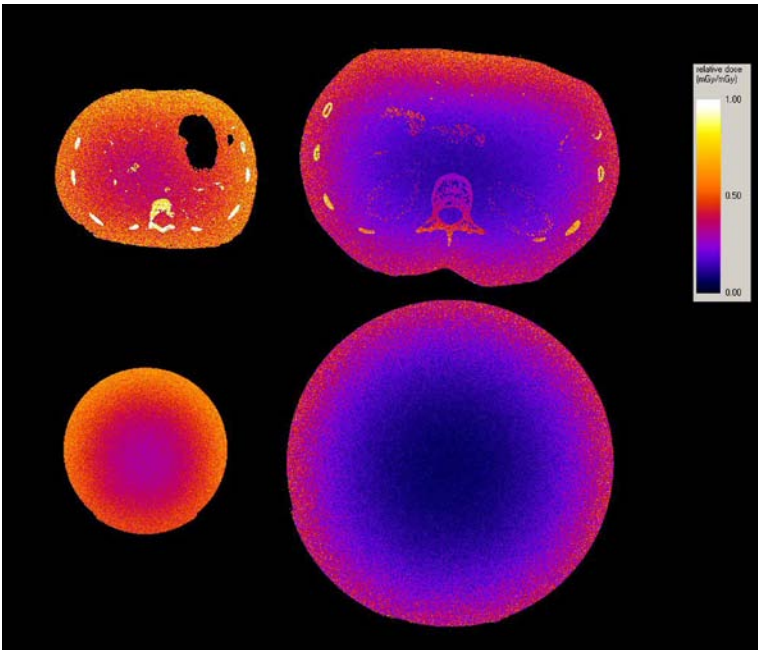


Figure 3. Dose distribution with the same scan parameters in different size patients and standard phantoms. (Image by: ImpactMC, CT Imaging GmbH, Erlangen, Germany)

Same scan parameters means that the dose display of the CT scanner would show the same dose level (measured in 32 cm phantom) for both patients. In this image there is a child in the upper left and an adult on the upper right corner, a 16 cm phantom (head) in the lower left and a 32 cm phantom (body) in the lower right corner. The dose distributions are colour coded so that blue means low dose level and yellow means high dose level. It can be seen from the image that the dose level indicated by the dose display (i.e. dose measured in 32 cm phantom, lower right) doesn't describe the real dose distribution in the patients very well.

Since the CT scanner dose display indicates the radiation dose in a cylindrical standard size acrylic phantom, it doesn't take the patient's size into consideration, and thus it doesn't indicate reliably the real radiation dose received by the patient. For this reason, determination of the patient's organ doses, effective dose and risk requires evaluation by a medical physicist.

With the same scanning parameters the dose level indicated for a 16 cm phantom is approximately double compared to dose measured with a 32 cm phantom.

When a CT-examination is planned and the scanning parameters are changed, the effect on the dose parameters can usually be seen on the dose display. The real time mA-modulation can further change the dose values during the scan. The final dose parameter values can be reviewed after the examination from the dose report that can be saved to the image archive. To interpret dose parameters the information of the phantom size used for calculation (16 cm head or 32 cm body) is needed. If the size of the dose phantom is not given, it should be verified from the scanner guidebook or requested from the CT-device supplier.

It's good to remember that the radiation dose of the examination cannot be reliably estimated based only on the mAs values, since different CT scanners have different kinds of filters depending on the scanner brand and model, and scanning is performed with different voltage levels. For these reasons, there may be big differences in the radiation output (mGy/mAs).

Iterative reconstruction

Reconstruction of CT images is based on *filtered back projection* (FBP). During the last few years *iterative reconstruction* has become more common in image reconstruction. In this method image is reconstructed by inverse problem solving and the image noise is reduced using modelling and repeating the calculation process. Reduced noise allows lowering the patient dose while the image quality remains adequate for diagnosis. Images produced by iterative reconstruction differ in appearance to some extent from CT images produced by FBP.

The iterative reconstruction algorithms and methods used by the scanner manufacturers (e.g. AIDR, ASiR, iDose, IRIS, Safire, VEO) differ. The latest iterative methods are model based, taking into account the physical features of the CT device and the scanning procedure. For this reason, the image quality (especially noise) can be improved considerably. This is a new and fast developing area of CT technology, and so there aren't yet publications that cover it, especially regarding the diagnostic advantages of the model based iterative methods.

The introduction of the iterative reconstruction program must be done by cooperation between medical physicists and radiologists in order to maintain the image quality diagnostic and to get the full advantage in dose optimization.

3.3 Using radiation shielding

The superficial tissues in the scan range, that are sensitive to radiation e.g. mammary glands, thyroid gland and lenses of the eye, can be protected with bismuth shields. The aim is to filter off the low energies of the beam that would otherwise absorb in to the patient's tissues. Bismuth shields may cause artefacts in superficial tissues under the shields, so using shields must be considered case specifically. A 1 cm thick cotton wool layer between the shield and patient's skin considerably reduces the artifacts. On the other hand, a too thick layer will reduce the shielding effect. Bismuth shields also affect the overall image quality, because they also partly prevent the radiation that has already gone through the patient from reaching detectors and so part of the patient exposure is lost and image quality is compromised. It's important that the use of bismuth shields is carefully considered, and they should always be chosen according to the patient's size so that they only cover the appropriate area. New CT scanners use different techniques that can reduce the dose e.g. to breasts by decreasing the tube current when the tube is in the anterior side of the patient.

Since AEC programs use attenuation information of the planning image for calculating the tube current beforehand, the bismuth shields should be placed after the planning image. This prevents the unnecessary increase of the tube current above the shield. If AEC changes the tube current also in real time during scanning, using a shield on the scan range may result in an unpredictable dose level, so their use is usually not recommended in these circumstances.

Lead shields can be used outside the scan range for protecting e.g. thyroid gland, mammary gland for girls and testes for boys. Shields should not be on the selected scanning area on the planning image, since the AEC program utilizes the density information obtained from the planning image.

Bismuth shields affect to AEC acoording to the technique used in each scanner, and thus the proper use of shields should be assured in operation training.

If the presence of the child's parent or other companion in the scanning room during the examination is necessary for a successful examination, the person must be carefully protected using a lead apron, thyroid gland shield and, if possible, lead glasses. This person should be placed in a point where scattered radiation is at minimum. Typically most of the radiation scatters to the 45 degree angle between the patient and scanning aperture, and least beside the aperture, where the CT scanner's own structures stop part of the radiation.

3.4 Preparation for the examination

Careful preparation of the CT exam reduces the risk of not succeeding in making a useful image. Procedures needed in preparation of a paediatric examination are listed below.

Reduce restlessness

- Describe the examination process to the child and the parent beforehand.
- One appropriately protected parent stays with the child, if needed.
- Sedation or general anaesthesia, if required.

Avoid pain

- Place the cannula in good time before the examination.

Practise cooperation

- Before the examination practising e.g. breath hold.
- Getting used to the table movements.

Prepare/plan the scanning carefully

- Defining carefully the scan range from the planning image.
- Patient positioning in the middle of the scanning aperture is very important for the correct dose modulation function. Off-centering may increase the patient dose considerably and worsen the image quality.

After the examination it is advisable to pay attention to the child, and it is usually a good idea to give a small reward, e.g. a sticker or a coloured pencil.

3.5 Literature

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4. Vendor specific features

This section gives more scanner-specific information from scanner manufacturers about matters related to optimization and paediatric examinations.

4.1 General Electric (GE)

Using radiation shielding
Shielding should be placed after planning image, when their effect on AEC can be avoided.

Automatic exposure control (AEC)
In the GE 3D modulation method, the tube current is controlled both while the rotation angle of the tube is changing (xy-modulation) and parallel to patient's z-axis (z-modulation). In automatic exposure control *the latest* planning image is always used for calculating the required mA values. If the latest planning image is a PA (or AP) projection, the dose level is a bit lower than if a lateral planning image is used as the basis for modulation. For the proper function of the mA modulation it is very important to center the patient in the middle of the scanner aperture. Wrong centering increases the patient's surface dose considerably and also affects the image quality.

The modulation technique used by GE (AutomA and Smart-mA) uses noise index (NI) for describing the noise level in an image filtered with a standard reconstruction filter in the middle of the scanned object. The NI value determines the accepted noise level in images and while selecting it the scan range, indication and the patient's size must all be considered. The tube current used for each rotation (mA-table) is defined with the NI value. For larger sized patients, a higher tube current is used in order to reach the desired image quality. The lower and upper limit for the used mA range is selected separately under the tube current menu (min mA, max mA). Before scanning it should be verified from the mA table that modulation works reasonably in the given mA range and is not saturated at the given max. or min. value. While selecting the NI value it must be considered that it is always defined for a specific reconstructed slice thickness. The software sets the mAs so that the user defined NI value of the images with slice thickness of the first reconstruction series is achieved. If the reconstructed slice thickness of the images used for diagnosis differs from the first reconstructed image series' (that is used for determining the image quality) slice thickness the desired NI must be altered accordingly. Typically the diagnistic slices are thicker so the NI can be higher for the first reconstruction series.

SFOV
The selection of SFOV defines the type of the beam shaping filter (small, medium and large). The lowest possible SFOV setting should always be used in examinations, taking into account the patient size.

Iterative reconstruction
GE has two different iterative reconstruction methods; ASiR (adaptive statistical iterative

reconstruction) and the newer VEO. With ASiR the percentage of the iterative weighting of the reconstructed image can be chosen, e.g. 40% ASiR weighting uses 40% iterative reconstruction and 60% conventional reconstruction technique (FBP). In the first ASiR version image noise is reduced by selecting manually the ASiR percentage. Reduced noise allows lowering the dose by increasing NI while using modulation, or by decreasing tube current while using fixed scanning parameters. Conversion factors must be used in calculating the amount of the changes. In the new ASiR version the desired dose saving percentage is set, compared to the images without ASiR using DRG (dose reduction guidance). After DRG selection, the scanner calculates automatically the needed ASiR percentage and tube current so that the noise level stays the same as in images acquired without ASiR. With small children the appropriately optimized scanning dose level is already low, and then the performance of DGR should be verified and ASIR percentage set manually, if required. It is recommend to define the scanner specific practice together with a medical physicist and an operations consultant from the scanner supplier. Selecting the dose saving and ASiR percentage is always an indication a specific solution. VEO is a new model based iterative reconstruction method and the potential dose saving is larger than with ASiR. The calculation time for VEO is long at present, and this restricts using the method in urgent examinations, for now.

4.2 Philips

Using radiation shielding

If bismuth shields are used they should be placed on the scan area after the scout scan, so that they won't affect the AEC. D-DOM ACE changes the tube current during scanning while the tube rotation angle is changing (x-y modulation), and while using this program bismuth shields should not be used in any situation.

Classification of scanning protocols

In Philips scanners, protocols are classified into groups: Infant (under 18 months), Child and Adult.

Dose display

In infant protocols' body region the dose calculation is based on a 16 cm diameter phantom, in other body area protocols on a 32 cm phantom, and in all head area protocols on a 16 cm diameter phantom.

Scanning parameters

When small objects are scanned the matrix size is important. Therefore, especially with children it is reasonable to use 768 x 768 and 1024 x 1024 image matrices. It is beneficial to change also the resolution to High or Ultra High mode with larger matrix size. Typically in examinations where a large matrix size can be profitable (e.g. lungs, inner ear, skeleton) mAs value does not have to be high, because the object's contrast is high with respect to the surrounding tissues.

Using High and Ultra High mode in paediatric examinations for other than high contrast objects is not recommended, because it requires increasing the mA value in these examinations.

While using a larger matrix size for reconstruction a sharp-filter is used and the slice thickness is kept low. The effect of changing the scanning parameters on patient dose can be tested before examination by using the simulation feature.

Automatic exposure control (AEC)

DoseRight (prev. ACS, automatic tube current control) suggests a mAs value individually for each patient that is user-editable even in the scanning phase. The scanner compares the water equivalent diameter calculated from the planning image to the reference patient's size of the scanner. If the patient has a larger size than the reference patient, the scanner suggests a higher mAs value and vice versa. The following table shows the reference patient sizes set to the newest scanner versions:

	Infant	Child	Adult
Boby	16 cm	20 cm	33 cm

If the patient size differs considerably from the reference patient, the scanner gives the user a notice, and the protocol can be changed before the actual image series begins.

- Z-DOM adjusts the tube current in z direction. The current profile is calculated before the examination on the basis of the planning image. The direction of the planning image (lateral, PA or dual) does not affect the AEC, and a planning image of one direction is sufficient. When using Z-DOM user sees the mAs min-mean-max-values before the scan and can adjust the max. value (thus, determining the maximum limit for mAs). When using Dual scout the proper tube current is calculated on the basis of the *first* image (lateral).
- D-DOM modulates the tube current while the tube rotation angle is changing (xy-modulation). Adjustment is real time, i.e. the attenuation difference between x- and y-direction is calculated based on the previous round.
- DoseRight Cardiac is a dose saving method used in cardiac helical scans. The phases to be reconstructed are defined before scanning, and the tube current is decreased for the areas that are not included in the phases to be reconstructed.

The following recommendations apply to Brilliance 64 version <3.5 and version iCT <3.2 scanners:

- infants and small children: Z-DOM (not DoseRight)
- pre-schoolers: Z-DOM (not DoseRight)
- older and larger sized children
  - Z-DOM (not DoseRight): neck/lung region
  - D-DOM or without modulation: upper stomach/pelvis and shoulder/neck
- adult-sized children
  - DoseRight or DoseRight+Z-DOM: neck/lung region
  - DoseRight + D-DOM: upper stomach/pelvis and shoulder/neck.

The following applies to Briliance 64 version ≥3.5, iCT version ≥3.2 and Ingenuity CT scanners:

- In addition to the above mentioned recommendations DoseRight function (automatic exposure control) can be used for all children, since these scanner versions have references also for small children.

Iterative reconstruction

The user can choose the iDose level in the scanning protocol: 1–7. The iDose level does not directly indicate the achieved dose saving as a percentage, but the dose reduction is done by adjusting mAs to match each iDose level according to the examination type. A table created for optimizing protocols gives the mAs levels corresponding to iDose-level for each examination type. It is recommended to use at least one degree sharper filter with iDose.

4.3 Siemens

Using radiation shielding

The AEC program uses attenuation information of the planning image for calculating the sufficient tube current beforehand. Bismuth latex shields should be placed only after planning image is taken. Since the tube current is adjusted also during scanning, it is important that the bismuth shields cover only the appropriate area and the shields should be chosen according to the patient's size.

Automatic exposure control (AEC)

In the Siemens CareDose 4D modulation method the tube current is adjusted both while the rotation angle of the tube is changing and along the patient's long axis (z-modulation). The software calculates the attenuation characteristics of the patient from the planning image and adjusts the tube current for each rotation before scanning. During scanning the thickness of the patient is inspected automatically real time in different directions and the tube current is adjusted even more precisely. For example, in lateral projection the patient can be thicker, and the current is adjusted higher than in AP projection.

In the CareDose 4D method, the only user adjustable parameter is Quality Ref mAs. The value of this parameter determines the noise level of the patient image. The image quality set by the Quality Ref. mAs is the image quality achieved for a normal sized (75 kg) reference patient when the given mAs-value is used. If the patient to be scanned is smaller than this, the mAs value is adjusted lower than the defined Quality Ref mAs value. In the same way, for a patient who is larger compared to a normal sized patient the mAs value is raised higher than the defined quality Ref mAs value. In paediatric protocols a normal sized patient is 25 kg and CareDose 4D works well with children up to 35 kg. If a child is remarkably larger (more than 40 kg), AEC can raise the tube current too high. Therefore, from the radiation protection point of view it is more reasonable to use a scanning protocol designed separately from the adult protocol for larger paediatric patients.

However, the newest scanners and some update versions of older scanners use an adult patient weighing approximately 70 kg also as paediatric reference patient. This should be considered while planning scanning protocols. The reference patient used in the software version should be verified before planning the paediatric scanning protocols.

The minimum tube current for a 16-slice scanner is 28 mA and for a 64-slice scanner 20 mA. CareDose 4D can adjust the tube current only higher than this.

Also a Care kV feature may be available in the new Siemens scanners. Based on the planning image and the selected scan type, the most suitable scanning tube voltage and the appropriate

Quality Ref mAs value are indicated. When using the Care kV feature, it should be always ensured that it works appropriately and that it does not (for example), raise the scanning voltage higher than necessary.

New Siemens scanners have the option of the X-care feature with which the tube current can be lowered while the tube is in front of the patient and thus dose to e.g. eyes, thyroid or breasts can be decreased without separate shielding.

Dose display

Siemens scanners calculate dose parameters also for paediatric examinations using the information based on adult dose phantoms (head 16 cm and body 32 cm).

Iterative reconstruction

When using the iterative reconstruction program a 1–2 grades sharper filter (Kernel) can be used because an iteratively reconstructed image is typically softer than an image reconstructed with the back projection method.

4.4 Toshiba

Using radiation shielding

Bismuth shields are placed after the planning image so they don't affect the mA-modulation calculation.

Classification of scanning protocols

Scanning protocols are classified into five groups: Adult, Child, Trauma, Whole body and Chest/Pelvis. Toshiba scanners have a specific examination tree structure (Child) where the paediatric examinations are defined. The children's examination tree structure appears automatically with paediatric patients (age is user selectable; default is 12 years)

Dose display

Dose display takes the used SFOV size into account: When SFOV is M or lower, the dose display is based on doses calculated with 16 cm diameter phantom. With higher SFOV values the dose display is based on a 32 cm diameter phantom.

Automatic exposure control (AEC)

In the SureExposure 3D program, the automatic tube current modulation is done both in z- and xy-directions, on the basis of anterior and lateral planning images. The desired image quality (SD = Low Dose+, Low dose, Standard, High Quality or High Quality+) is selected. The accepted noise level in images depends on the selected image quality and the region to be scanned. For paediatric patients there are specific dose modulation curves that are not dependent on the adults' curves.

Since SureExposure is based on the selected noise level, the tube current level depends on many different parameters e.g. the used primary reconstruction kernel. For example, a sharp

FC13-kernel results in a higher tube current than softer ones, FC12 or FC10.

If the SureExposure 3D AEC is not used, the noise level and minimum and maximum values for tube current can be selected separately in paediatric examinations. The scanner then functions between these values. It's also possible to switch off the xy-modulation and use only Z-direction modulation.

Iterative reconstruction

The Toshiba AIDR+ automatic iterative calculation also works for paediatric patients.

Miscellaneous

For paediatric patients there are specific FC-kernels (Toshiba's patent) both for babies (infant) and child patients (child).

Toshiba scanners have a simulation mode (Scan Simulator) which the effect of can be used for evaluating the effect of scanning parameters beforehand. Also an example image appears for which the noise level depends on the scanning parameters used.

5. Head region

5.1 Head

The primary method for paediatric brain examinations is magnetic resonance imaging (MRI). CT is indicated in an acute situation and when MRI is contra-indicated or in rare special cases (e.g. CT angiography in imaging of an acute vascular lesion). Ultrasound examination with good technique through anterior fontanelle is usually adequate for babies e.g. in assessing ventricular size and cerebral problems due to prematurity. However, it should be remembered that ultrasound does not reliably exclude all types of traumatic lesions possibly requiring neurosurgical intervention. Cerebral ischemia in children is examined with MRI, and CT perfusion imaging used for adults should not be used for children because of the excessive radiation dose.

Head trauma imaging is discussed within item 10.1.

Indications

- Suspected acute brain incident (e.g. intracranial haemorrhage).
- Imaging ventricular size in patients with ventriculo-peritoneal shunt if the fontanelle is already closed and MRI is not available (see item 5.2).
- Surgical intervention planning in cases of premature closure of the cranial sutures (see item 5.3).

Performing the examination

The examination can be performed either with axial slices or with helical scanning. If possible the gantry should be tilted to avoid the eyes. Image quality should be good enough to differentiate grey and white matter (both the cortical and deep gray matter, i.e. basal ganglia). I.v. contrast medium is very rarely indicated; any additional information needed is best acquired using MRI.

5.2 Head scanning in the assessment of ventriclular size

As long as the fontanelle is open even a little, the ventricular size can be determined by ultrasound. MRI is preferred when examining older children. If it is not possible to use MRI, CT should be performed as a low dose examination. It is important to note that fully optimizing the scan parameters will result in patient dose significantly lower than in routine head scan.

Indications

- Suspected ventricular dilatation in ventriculo-peritoneal shunt malfunction.

Performing the examination

Since the image quality is needed only for assessing the ventricle size, quite noisy images are sufficient for diagnosis. Thus remarkably lower scanning parameters can be used than in routine head CT. Scanning 4–5 slices at the ventricle level is enough for diagnostics. In the planning image one slice is placed at the level of the ventricular shunt tip in order to confirm its localisation.

5.3 Scanning the cranial sutures

Diagnosis of premature closure of the cranial sutures is usually clinical (Duodecim 2007). If necessary, ultrasound examination or plain x-ray can be used according to radiologist's instructions. Ultrasound (at least a 7.5 MHz probe) has been shown to be reliable especially for examination of single sutures (e.g. plagiocephaly). CT is usually needed only for surgical planning.

Performing the examination

CT is performed according the instructions of the institution performing the operation in order to ensure adequate 3D-reconstructions. The image quality needs to be adequate only to delineate the bony structures.

5.4 Literature

1. Dunning J et al. Derivation of the children's head injury algorithm for the prediction of important clinical events decision rule for head injury in children. Archives of Disease in Childhood 2006; 91: 885–891.
2. Kuppermann N et al. Identification of children at very low risk of clinically-important brain injuries after head trauma: a prospective cohort study. Lancet 2009; 374 (9696): 1160–1170.

6. Ear, nose and throat region

ENT region is usually scanned with CT to examine the bony structures; so the natural contrast of bone allows low scanning parameters. A low-dose technique should be used especially when scanning paediatric facial bones and paranasal sinuses. Scanning parameters should be optimized according to patient's size. With good optimization the patient dose might be as low as with a few conventional radiographic images of the same region.

6.1 Paranasal sinuses

In complicated or chronic sinusitis CT provides a great deal more information of the anatomy than conventional radiography. Also cone beam CT can be used for surgical planning.

Indications

- Surgical planning (FESS-TT): surgical mapping before operation, low-dose-CT
- Complicated sinusitis (epidural abcess or orbital subperiosteal abcess): surgical mapping before operation if needed, to allow surgery in navigator control: low dose CT
- Suspected tumour: imaging bony structures in addition to MRI, good quality images of both bone and soft tissues are needed.

Performing the examination

Thyroid shielding is preferred when possible. Bismuth shielding for eyes cannot be used if the surgery is performed in computed navigation control. Computed navigation is based on recognising the facial surface which will be distorted if shielding is used.

The examination is performed as a helical scanning in axial direction, 1mm slices are reconstructed in axial, coronal and sagittal planes using both bone and soft tissue algorithms. Scanning voltage of 80 kV is usually adequate for all patients to delineate the bony structures of the ENT region. When performing low dose scans the effective mAs can be 17–25 mAs according to the child's size.

6.2 Ear region

CT examination of the inner ear is a special examination that is requested mainly for surgical planning.

Indications

- Cochlear implantation surgery: both MRI and CT are performed.
- Further imaging of an inner ear anomaly in addition to MRI. Many of structural anomalies of the inner ear, such as anomalous auditory ossicles, or auditory canal atresia can only be visualized with CT.
- Cholesteathoma is diagnosed clinically, imaging is needed only in special cases; CT is used mostly for surgical planning.
- Complicated infection (e.g. subperiosteal or epidural abcess, sinus thrombosis): MRI is the first-line examination for children, but CT might be needed to examine bone destruction.

Performing the examination

In spite of developed reconstruction techniques, careful positioning of the patient head is necessary to keep the scan length short in order to minimize radiation dose. Head should be positioned straight to scan the temporal bones within the shortest possible scan range, from the tip of the mastoids to the upper edge of the tympanic cavity. 0.5 mm slices are reconstructed in true axial (skull base plane) and coronal planes. Both bone and soft tissue algorithms are used to examine inflammatory lesions and congenital anomalies.

6.3 Facial bones

Facial fractures are uncommon in children because of the craniofacial proportions and small paranasal sinuses. Coventional radiography of the facial bones has been found unreliable with paediatric patients, and thus CT is the first-line examination when facial fracture is clinically suspected. Suspected nasal bone fracture should not be imaged at all.

Orbital fractures are usually in the orbital roof in children under 7 years of age, and in the orbital floor in older children because of the development of the paranasal sinuses. Orbital fractures are rarely treated surgically in children, but inferior rectus muscle entrapment (diagnosis made clinically) requires operation.

Indications

- Suspected clinically significant (requiring surgical treatment) facial bone fracture: low-dose examination.

Performing the examination

The examination is performed as helical scan (low-dose examination is recommended in the literature, e.g. Morales et. al.). Axial, coronal and sagittal reconstructions are done both with bone and soft tissue algorithms. A 1–2 mm reconstructed slice thickness may be needed to examine the facial bones.

6.4 Literature

1. Morales JL, Skowronski PP, Thaller SR. Management of pediatric maxillary fractures. Journal of Craniofacial Surgery 2010; 21 (4): 1226–1233.
2. Mulkens TH, Broers C, Fieuws S, Termote JL, Bellnick P. Comparison of effective doses for low-dose MDCT and radiographic examination of sinuses in children. American Journal of Roentgenology 2005; 184 (5): 1611–1618.

7. Neck region

CT of the neck is indicated only in special cases. The primary modalitities used in the examination of this area are ultrasound and MRI. Ultrasound may not demonstrate the deep inflammatory lesions, and in children the poor visualization of fat lines makes the soft tissue differentiation in CT difficult. If MRI is not possible, contrast medium enhanced CT is recommended.

Spine trauma imaging is discussed in item 10.2.

8. Chest region

Helical scanning is usually used when performing CT examinations of the chest. Exception is HRCT examination, which is performed with single thin slices of the whole lung or the region of interest.

The use of contrast medium should be considered case-by-case basis. The use of i.v. contrast may help to delineate mediastinal structures especially in small children, but should be considered individually. With older children, and especially in control studies, it is rarely needed. Contrast medium is not useful in detecting metastases in lung parenchyma.

CT angiography is an alternative option to MRI examination especially when examining neonates (because of their small vascular structures). Lowering the tube voltage (kV) increases image contrast, and is recommended especially in angiography. Lowering kV may reduce the patient dose, but the increased noise may require increasing the tube loading (mAs).

Spine trauma imaging is discussed in item 10.2.

8.1 Thorax

Chest CT is usually used to diagnose and follow-up metastatic disease, but MRI is often better in diagnosing mediastinal tumors. This is especially true for posterior mediastinal tumors where involvement of the spinal canal can be crucial information. For pulmonary abscesses, especially in follow-up, the accuracy of MRI is often adequate. When assessing pleural fluid, ultrasound is the modality of choice, and CT has not been shown to give more information in the characterization of the fluid.

Imaging of the bony structures is discussed in items 10.3. (Trauma) and 11.5 (Spine).

Indications

- Complicated infection
  - For lung abscess detection/follow-up MRI – examination must be considered.
  - Ultrasound for pleural fluid detection and characterization.
- Detection and follow-up of tumors and metastases. MRI is often a better choice, especially with posterior mediastinal and chest wall tumors.
- Examination of parencymal and mediastinal structural anomalies (MRI examination should be considered when possible). Ultrasound is often the best modality to visualize the thymus.
- CT angiography:
  - small vascular structures (less than 4 mm)
  - pulmonary embolism
  - vascular structures and heart, when MRI is not possible due to a long sedation or metal implants.

Performing the examination

With modern multi-slice equipment and fast scanning, breath hold is not necessary with small children. Sedation often provokes athelectasis which may be difficult to prevent. In such cases examining the child in prone position may aerate the athelectatic posterior parts of the lung.

Scan range is based on the indication. Usually the whole lung region from apices to just below the pleural angles is scanned, but over-extending the scan range should be avoided. The good natural contrast of the lungs allows the use of both low tube voltage (kV) and loading (mAs) to reduce the patient dose. Tube voltage of 80 kV is usually adequate for children under 10 kg and 100 kV for children under 60 kg.

The need of i.v.contrast medium depends on the indication; lung metastases can be visualized without. However, contrast medium should be used at least in the diagnosis of complicated pneumonia and tumors. It can also be used to outline the mediastinal structures, especially with small children (thymus). Unionized iodinated contrast medium with usually 300 mg I / ml is used when needed. Volume of contrast medium is 1.5–2 ml/kg under 20 kg and 1–1.5 ml/kg over 20 kg up to 50 ml. Injection rate depends on the size of the child, the vessel caliber and the indication of the scanning; usually 1–3 ml/s. An automatic injector pump should be used, if possible. Scan delay should be set to 20–30 s (depending on the size of the child), in order to visualize all vascular structures.

8.2 High-resolution CT

High-resolution Computed Tomography (HRCT) with thin interspaced slices is a valuable tool in the diagnosis of diseases of the lung parenchyma and the airways. HRCT is more sensitive than plain film chest x-ray in the detection of diffuse interstitial lung disease, and more accurate in characterizing them. The spectrum of the diffuse interstitial lung diseases is different with children than with adults. Both clinical and radiological presentations are less specific with children, and even histopathological differential diagnosis is not always straightforward; thus accurate diagnosis is challenging.

The aim of an HRCT examination is to assess the presence and extent of the lung pathology, characterize the lesions, restrict differential diagnosis and demonstrate a good site for biopsy.

The secondary pulmonary lobule is a fundamental unit of lung structure, the smallest structure that is surrounded by connective tissue septa and can be visualized in HRCT. It consists of approximately ten pulmonary acini with vessels, and understanding its anatomy is essential in interpreting the HRCT examination and classifying the findings.

Indications for pediatric HRCT

- Normal chest radiograph with severe/unexplained lung symptoms, e.g.
  - unexplained fever in an immunocompromised patient
  - unexplained dyspnea/oxidation failure
  - discrepancy between the pulmonary function tests and the chest radiograph.

- Abnormal but non-specific chest radiograph
  - Ill-defined nodules, opacities or suspected interstitial lung disease
  - biopsy site selection.
- Detection of bronchiectasis.
- Detection of sequelae of infection in a child with persistent symptoms
  - bronchiolitis obliterans (BO) or bronchiectasis.
- Cystic fibrosis: staging, response to therapy (MRI feasible in follow-up).
- BPD (bronchopulmonary dysplasia): evaluation of the severity of the disease in special cases.
- Follow-up of diffuse interstitial lung disease or airway disease.

HRCT technique

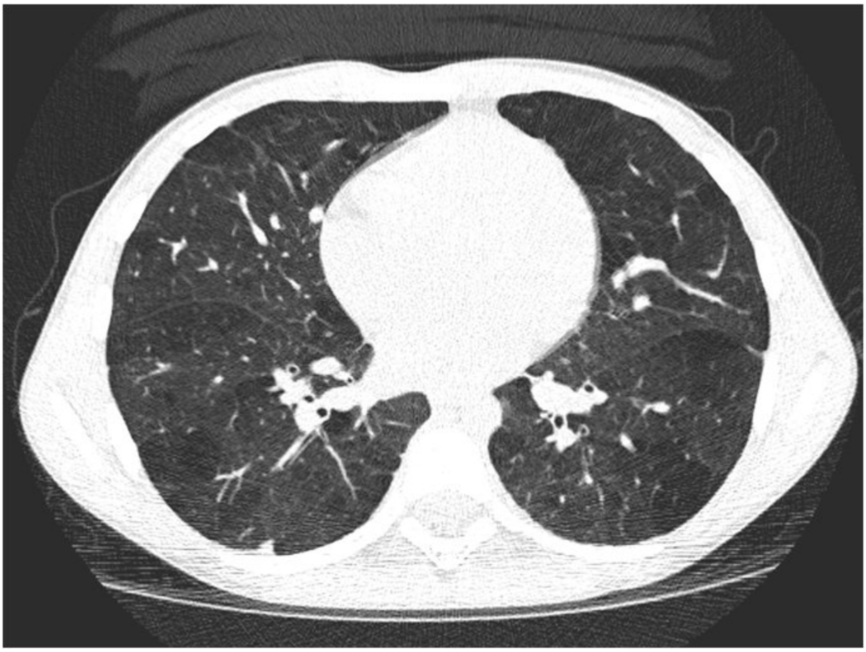
Breath hold is necessary to achieve good quality images, and this is why small children usually need general anaesthesia and scanning in breath control. Good cooperation with the anaesthesia personnel is important. For a successful examination the interval between breath holds can be increased e.g. to 15–20 seconds.

If general anaesthesia is not possible due to the child's condition, the examination can be performed during quiet breathing, but with less accuracy. For expiratory images the child can be scanned in lateral decubitus position, when the non-dependent lung appears as if in inspiration and the dependent lung as if in expiration.

The axial HRCT images (1–1.5 mm) are reconstructed on a high spatial resolution algorithm (edge/bone) in inspiration and expiration. The acquisition time should be as short as possible in order to avoid the motion artefacts. The suitable slice interval in primary examination is usually 10 mm in inspiration. In follow-up examinations the slice interval can be extended to 15–20 mm. The 3–5 expiratory slices are usually obtained so that the highest is acquired above the aortic arch and the lowest approximately 1 cm above the upper diaphragm. The purpose of the expiratory scan is to show the air trapping, thus worse image quality is acceptable than in inspiration scans. This should be considered when adjusting the scan parameters. It may be necessary to acquire few additional scans in a prone position due to athelectasis of the posterior lung.

Image windowing should be adjusted according to the viewing devices and conditions. However, it is important to always use the same windowing, to allow image comparisons.

If volumetric acquisition is needed in addition to HRCT, adequate HRCT images can usually be reconstructed with modern scanners from the helical scan raw data, and a separate scan is not needed. Since with edge-enhanced algorithms the image noise is higher, an increase of the tube current may be necessary to maintain adequate diagnostic quality. Contrast medium is not used with HRCT.



Figures 4 and 5. Example images of HRCT slices. The upper is during inspiration and the lower during expiration.

8.3 Chest CT-angiography examinations

Cardiac structures can be better examined with ultrasound than CT, but the visualization of the vascular structures can be inadequate. In neonates especially, abnormal vessels can be so small that the resolution of MRI is not adequate either. CT examination provides information also about the bronchi and lung parenchyma, which can be useful especially with neonates.

Indications

- Small vascular structures (less than 4 mm).
- Pulmonary embolism.
- Heart, when MRI is not possible due to long sedation or metal implants.

Performing the examination

Anaesthesia in needed for small children, but breath hold is usually not necessary. Scanning without contrast medium is usually not useful in CTA. In cardiac imaging the heart may sometimes be scanned twice, if the enhancement of different structures at different phases is needed.

The cubital vein should be used for fast injection to get sufficient concentration of contrast medium in the desired strucures. Automatic injection should be used whenever possible. Scanning delay depends on the interest: e.g. the pulmonary arteries or veins, the aorta or all vascular structures at the same time. The delay depends also on the child's size and the injection site. Children have fast circulation, and therefore assessing the injection delay is difficult. Automatic measurement of the contrast medium concentration should be used if possible. When scanning very small children, the scan delay needed by the protocol might be too long. In these cases, the required delay to the beginning of the scan must be estimated. If the scan is started right at the end of the injection, all vascular structures are usually moderately well enhanced. CTA is performed with a fast contrast medium injection and then flushing with a fast saline injection. When scanning babies the injection rate of 1–1.5 ml/s is usually enough, and with older children 2–3 ml/s. Injection rate of 4–5 ml/s may sometimes be necessary but usually only for children over 10 years of age.

8.4 Literature

1. Copley SJ, Padley SP. High-resolution CT on paediatric lung disease. European Radiology 2001; 11 (12): 2564–2575.
2. García-Peña P, Boixadera H, Barber I et al. Thoracic findings of systemic diseases at High-resolution CT in children. Radiographics 2011; 31 (2): 465–482.
3. Klussmann M, Owens C. HRCT in pediatric diffuse interstitial lung disease – a review for 2009. Pediatric Radiology 2009; 39 Suppl 3: 471–481.
4. Kuhn JP, Brody AS. High-Resolution CT of pediatric lung disease. Radiologic Clinics of North America 2002; 40 (1): 89–110.
5. Webb WR. Thin-section CT of the secondary pulmonary lobule: Anatomy and the image – The 2004 Fleischner lecture. Radiology 2006; 239 (2): 322–338.

9. Abdominal region

Ultrasound is the modality of choice in paediatric abdominal problems. MRI has widely replaced CT in abdominal imaging in paediatrics, although long scanning times often require general anaesthesia. When examining abdominal tumours, CT is seldom used, and also in cancer follow-up a combination of chest CT and abdominal MRI is good practice.

The small amount of abdominal fat and thus poor natural contrast make the visualization of different structures challenging, and thus i.v. contrast medium is usually necessary. There is no clear consensus in the literature about the filling of the intestine with radiolucent or radio-opaque contrast medium, and the need depends on the indication of the scan. In Finland the diagnosis of appendicitis is usually based on clinical findings, and ultrasound can be used to aid in differential diagnostics. When examining paediatric acute abdomen, CT is seldom needed. The exception is urinary tract calculi, which are rare in children. Then CT is performed as a complementary examination to ultrasound with very low dose and without i.v. contrast medium.

To image abdominal vascular structures CT is still an important method, although the indication is often related to complicated transplantation surgery. Also the use of gadolinium in MRI examination can be contraindicated for these patients, because of the related risk of nephrogenic systemic fibrosis (NFS).

Indications

- Trauma with clinical signs of abdominal injury or an unstable patient.
- Complicated infection when ultrasound does not give enough information and MRI is not available.
- Suspected urinary tract stones, if ultrasound does not give enough information (low-dose examination without contrast medium).

Performing the examination

With modern fast CT scanners breath hold is not obligatory but it is recommended. The need for anaesthesia should be considered case-by-case considering the child's developmental level. In most cases the examination is performed with i.v. contrast medium, and thus the child should have venous access.

Filling the bowel with water or positive oral contrast medium should be considered case-by-case basis. However, the children coming to CT examination are usually so ill that they cannot drink the contrast medium, and trauma patients are always scanned without p.o.contrast medium. Radio-opaque orally administered contrast medium can be utilized mainly to diagnose abdominal abscess. The smaller the child is, the less he/she has abdominal fat and the more difficult it is to follow the bowel loops. Thus it is difficult to see whether the fluid seen in the image is inside or outside the bowel. 10 ml of water soluble 300 mg I /ml contrast medium added to 400 ml water or juice can be used as oral contrast. This is given 20 ml/kg divided to 2 doses. The passage time of the contrast in small bowel varies a lot in children, but has been shown to be approximately 1.5 hours. Thus, the first dose is given 1.5 hours and the second 15–30 mins before scanning.

Unionized i.v contrast medium of 300 mg I /ml is usually used, volume of 2 ml/kg. Scan delay depends on the child's size, the cannula used and the injection rate. Different methods to calculate the injection rate (ml/s) have been published, e.g.: weight (as kilograms) · 0.1 or (injection volume (ml)) / (delay(s)-15 s).

Enhancement of the liver parenchyma is sufficient, when contrast is seen in the hepatic veins. According to some studies, it takes 50 s from the beginning of the injection for small children and 60–70 s for older children. If automatic measurement of the contrast medium concentration is used, the ROI is placed on the upper part of the abdominal aorta, and scanning is started – depending on the child's size 30–50 s after the concentration in the aorta is sufficient.

Scan region is from diaphragm to symphysis, but depends on the indication. Scanning the urinary tract is started from the upper end of the kidneys. Over-extending the range should be avoided.

Reconstructed slice thickness of 2–3 mm is often good; even 4–5 mm (especially for bigger children) is possible. Image reconstruction is usually soft tissues weighted. However, in trauma cases bone reconstructions are also needed. Lung windowing may aid in showing air outside the bowel. Reconstructions should be done also in the coronal plane, which may help in assessing the bowel loops.

With children the small amount of abdominal fat makes assessing the bowel and its walls more difficult. Sometimes it is impossible to differentiate the appendix from the intestine. Differentiating a slightly inflamed intestinal wall from normal may also be tricky.

9.1 CT-angiography of the abdominal region

Indications

- Scanning abdominal vascular anomalies in special cases, if ultrasound does not provide enough information and MRI is not possible or its resolution is not sufficient.

Performing the examination

A large cubital vein should be used for injection to get sufficient concentration of the contrast medium. Usually 2 ml/kg of 300 mg I /ml unionised contrast medium is used. Scan delay depends on the child's size, the cannula used and the injection rate. Automatic injection should be used whenever possible. CTA is performed with a fast contrast injection and then flushing the contrast medium with equally fast saline injection When examining babies, the injection rate of 1–1.5 ml/s is usually enough, and with older children 2–3 ml/s. An injection rate of 4–5 ml/s may be sometimes needed but usually only when imaging teenagers. It may be difficult to determine the contrast delay, because of the fast circulation. Automatic measurement of the contrast concentration should be used, if possible. The ROI is usually placed on the upper part of the abdominal aorta. When scanning very small children the scanner's shortest delay from the aortic enhancement to actual scanning can be too long. Therefore the scan can be started right at the end of the contrast medium injection, and all vessels are usually moderately well enhanced. Per oral contrast medium is not used in CTA.

9.2 Literature

1. Frush DP. Pediatric abdominal CT angiography. Pediatric Radiology 2008; 38 Suppl 2: 259–266.

10. Trauma

CT has a central role in the imaging of severely injured children. The primary purpose of imaging is to recognize life threatening injuries. However, paediatric patients should not be scanned routinely with CT except in cases of high-energy trauma. The need of CT should always be considered case-by-case basis. Instead of whole body scanning the paediatric trauma CT is often focused to for example abdominal area.

Although the sensitivity of ultrasound is only about 55% also in children, combining it to clinical examination can raise the sensitivity to 100%. However, ultrasound has a remarkably larger role in paediatric imaging than in adults. When examining haemodynamically stable patients and FAST US (focused assessment with sonography for trauma) is found normal, a more thorough SLOW (second look if otherwise well) ultrasound examination has been suggested instead of CT.

The decision of CT examination is done based on clinical findings (pain, haemodynamic stability, neurologic signs). Also the related injuries affect the decision, e.g. spinal or pelvic fracture may require CT.

10.1 Head trauma

Since especially in small children assessing the level of consciousness due to injury using the GCS (Glasgow Coma Scale) scale is very unreliable, different rules have been created to recognise those patients who need CT. The best validated guideline is the PECARN rule (Pediatric Emergency Care Applied Research Network) which, however, recommends CT examination quite easily. The following list of indications for head CT examination follows the recommendations from a British study (Dunning 2009, CHALICE rule). Using these criteria the sensitivity to predict a clinically significant brain injury was 98% and specificity up to 87%.

- GCS <14, or <15 if under 2-years old
- drowsiness or abnormal behaviour
- positive focal neurology
- witnessed loss of consciousness over 5 min
- history of amnesia over 10 min
- signs of basal skull fracture
- large (>5 cm) bump/bruise in scalp if under 2-years
- seizure after head injury
- recurrent/increasing vomiting
- increasing headache
- high-energy injury (e.g. traffic accident >50 km/h, falling >3 m)
- multiple injury.

10.2 Spinal trauma

When examining spinal trauma it should be remembered that children may have a significant spinal injury without abnormalities in bony structures (SCIWORA).

Indications

Cervical spine

- Clinical suspicion of cervical spine fracture.
- Plain radiography equivocal or suspicion of unstable fracture.

In a multi-centre study (Leonard et al 2010) the recommended criteria which indicate increased risk of cervical fracture were:

- loss of consciousness in trauma patient (also intoxication)
- focal neurologic findings
- complain of neck pain
- Torticollis
- substantial injury of the body
- predisposing condition (e.g. Down's syndrome, spondyloepiphyseal dysplasia (SED))
- diving as trauma mechanism
- high-energy injury.

Thoracic and lumbar spine

- Plain radiography equivocal or suspicion of unstable fracture.

10.3 Trauma of thorax and abdomen

Indications

- Clinically suspected thoracic injury or laceration of parenchymal abdominal organ.
- Further evaluation of a parenchymal organ injury detected in ultrasound examination.
- Further imaging of findings in chest radiography.

10.4 Performing trauma examination

Head is scanned without contrast medium with helical or axial scanning. In helical scanning the dose to the orbital lens may increase if overranging is not prevented. However, helical scanning allows scanning of the facial structures at the same time if needed, thus the dose can be lower than when scanned separately.

Cervical spine can be scanned with the collar in place. Scanning of the body should be performed hands above head, if possible. Radiation exposure is lower if the body region is scanned as one stack. The examination of the body is performed with i.v. contrast (2 ml/kg, 300 mg I /ml). Bowel contrast is not used. If CT-angiography (e.g. lower extremities) is needed, is should be performed before the scanning of the body. Then the contrast for angiography can be utilized in the imaging of the body region.

The thoracic scanning should be timed so that there is a good contrast concentration in the major vessels.

Good enhancement of the parenchymal organs is essential in abdominal scanning. Scan delay varies significantly depending on the child's size and haemodynamics (ca 10–30 s for thoracic and 50–70 s for abdominal region). Alternatively a two phase injection (2 ml/kg) can be used. First 80% of the contrast is injected to enhance the abdominal organs and then 20% just before the scan to enhance also the major vessels at the same time. The whole body is scanned as one stack. Thus the abdominal organs are enhanced and there is also good contrast in the major vessels. If renal collection system injury related to kidney trauma is suspected, delayed scan is performed at kidney level after 5–15 minutes to see the possible extravasation of the contrast. When examining babies, the injection rate of 1–1.5 ml/s is usually enough, and in older children 2–3 ml/s. Injection rate of 4–5 ml/s may be sometimes be needed but usually only in teenagers.

10.5 Literature

1. Dunning J et al. Derivation of the children's head injury algorithm for the prediction of important clinical events decision rule for head injury in children. Archives of Disease in Childhood 2006; 91: 885–891.
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11. Orthopaedic examinations

Orthopaedic CT examinations are mainly performed for the surgical intervention planning. The natural contrast of bones usually allows low tube current (80 kV) also for bigger patients. On the other hand, it may be necessary to increase the scanning parameters if there is metal inside the scan range from previous operations.

11.1 Measuring leg length discrepancy from the planning image

Leg length difference is examined clinically, and imaging is used when surgical intervention (epiphyseodesis) is planned. The purpose of imaging is to find out whether the length difference is more pronounced in the femoral or tibial region. A CT planning image is the recommended imaging method due to its low radiation exposure. But because the scan is done supine, the possible effect of the foot anatomy or mal-alignment of joints to the length discrepancy cannot necessarily be seen.

Indications

- Evaluation of leg length discrepancy, when epiphyseodesis is planned, and the clinically determined difference is more than 2 cm.

Performing the examination

Measuring is done on the planning image. If possible, the planning image is acquired in the PA direction. Often 80 kV is enough when bony structures are evaluated. The patient is positioned with legs side by side in a similar way, pelvis as straight as possible, feet forward, no external rotation, toes together (supports can be used around the knees or beside the feet).

11.2 Joints

It is difficult to place only one joint (e.g. ankle) in the isocentre of the scanner so that AEC would work properly, and thus fixed scanning parameters instead of AEC should be considered.

Indications

- Further evaluation of fracture of the articular surface to plan surgical treatment.

Performing the examination

Bony structures have high natural contrast, and thus lower scanning parameters can be used. 80 kV is sufficient as tube voltage, and a low mAs value is enough especially for scanning small joints. The scan range should cover only the joint area with the whole fracture area and associated growth plates. It may be necessary to scan the elbow beside the body, if it cannot be raised over the head. Then both kV and mAs must be increased almost to the level used for body scanning. The so called “extremity CT scanner” can be used, if available. It allows e.g. scanning only the elbow without radiation exposure to the body.

11.3 Growth plate scanning for evaluation of growth arrest

Indications

- Evaluating the size of growth plate fusion detected in radiography, for surgical treatment planning.

Performing the examination

The scan range should cover only the growth plates of the joint of interest. It may be necessary to scan the elbow beside the body, if it cannot be raised over the head. Then both kV and mAs must be increased almost to the level used for body scanning. When scanning the extremities a so called extremity CT scanner can be used, if available. It allows e.g. scanning only the elbow without radiation exposure to the body. Slices parallel to the growth plate are reconstructed from the scan. The percentage of the prematurely ossified part of the growth plate area is measured.

11.4 DDH in cast

Indications

- Verifying the position of the femoral head in a child with pelvic cast for DDH, when MRI is not possible.

Performing the examination

The cast stabilizes the child's pelvis so that the examination can be performed without sedation. The scan range is from the upper edge of the acetabulum just below the femoral head. The scanning can be performed with 2–3 axial slices or a short helical scan. Low voltage (80 kV) and low mAs are enough to see the bony nucleus in the bony acetabulum. If examination of the cartilaginous structures is needed, it is done with a MRI examination.

11.5 Spine

Indications

- Equivocal or unclear fracture in plain radiography.
- Suspected unstable spinal fracture.
- Precise anatomical clarification for surgical planning for scoliosis or vertebral anomalies.

Performing the examination

With fractures, the scan range is determined by the conventional radiography findings. Over extending of the scan range should be avoided. For the planning of surgical treatment the operating surgeon defines the scan range according to the extent of the instrumentation. Also pedicles of normal vertebrae should be inside the scan range, and vertebrae should be able to be named. If CT scan data is used to make 3D plastic models for surgical planning, raw data should be saved and sent to the unit that makes the models.

12. Hybrid nuclear medicine examinations

Computer tomography can be utilized in hybrid nuclear medicine imaging for three different purposes:

- attenuation correction
- anatomical localisation of the radio-medicine uptake
- as a diagnostic examination.

These differ from each other regarding the required image quality and thus the patient dose. The required image quality must be defined beforehand in order to optimize the examination. The predefined paediatric protocols of the device manufacturer are typically designed to produce a good image quality, and they are not optimized in relation to the patient dose.

An attenuation correction map of the scan region can be produced with the CT equipment. It allows correction of the radio-medicine's radiation attenuation in the patient. The electron density information of the CT image is used to create the attenuation correction map. Scanning with very low current and dose is sufficient to produce the attenuation map. Practically, the smallest scanning parameters that the CT scanner can produce can usually be chosen, especially with small children. Radiation attenuation in small children is minimal and for this reason in SPECT (single-photon emission tomography) examinations the attenuation correction is usually not necessary. Computational attenuation correction methods can be used for fairly homogenous objects (e.g. a child's head). Attenuation correction is always required to analyze PET (positron emission tomography) images.

To localize the pathological radio-medicine uptake, image quality should be good enough to distinguish the anatomical structures. This image quality is often sufficient also to replace the diagnostic control CT examination, especially in chest region.

Diagnostic image quality in nuclear medicine CT-examination is required only if it can replace the diagnostic CT examination, that would be otherwise required. For diagnostic purposes a noisier image quality is usually adequate in paediatric CT examinations than in adults' examinations. The required image quality should be optimized together with a radiologist specialized in paediatric imaging. When defining the image quality, it should also be considered whether a CT examination is needed e.g. for external radiotherapy dose calculation or future image fusions. Using contrast with attenuation correction scanning may cause over-correction. Therefore, i.v. contrast cannot usually be used with attenuation correction scanning.

Indications

- Most children's cancer types accumulate F-18-fluoro-deoxy-glucose (F-18-FDG) which is the most common marker used in PET-CT. In primary diagnostics PET-CT should be considered with
  - Hodgkin's lymphoma
  - non-Hodgkin's lymphoma with a atypical primary tumour/metastases
  - extramedullary leucaemia, if primary tumour is not known
  - soft tissue sarcoma

- MIBG negative neuroblastoma
- yolk sac tumour
- Langerhans cell histocytosis.

- Follow-up imaging is indicated only if recurrence or metastazing affects the patient's treatment. With recurrent disease PET-CT can be used to plan radiotherapy or determine the biopsy site.
- For treatment response PET-CT should be considered in non-Hodgkin's lymphoma, when a poor response is suspected in conventional imaging. Information about the activity of the remaining tumour is then achieved.
- Combining CT to paediatric SPECT examination is rare, but in some cases, e.g. gamma scanning of the stomach mucosa, CT localization can give more clarity.

Performing the examination

The need for diagnostic CT should be found out before the hybrid examination to avoid unnecessary imagning. It can often be replaced with the CT examination performed with the nuclear medicine examination.

The nuclear examination should be performed first, if possible, because in most cases it can be repeated if required. If the CT examination has been performed first, and the patient moves during the nuclear medicine examination, the CT cannot be used. However, in PET-CT examinations the CT is performed first, and PET scanning is planned based on it. Thus, if the patient moves during the PET scanning, the previously acquired planning image and possibly also the low-dose CT may be spoiled. Some of the isotopes used in PET examinations are fast-decaying, and one cannot repeat the examination many times. Supporting the patient carefully during sedation is also important for a successful examination.

The long scan times should be taken into account in nuclear medicine examinations. This is why small children are typically scanned under general anaesthesia. The patient should be carefully supported also for the scanning, since nerve damage has been reported after a long anaesthesia.

The parents can stay beside the child during the nuclear medicine examination, and a suitable entertainment (a DVD, a book…) is usually enough to keep the child calm. The parents don't need to leave the child alone for radiation protection reasons, but during the CT examination they should move further away, if possible, and be shielded appropriately (a lead vest, thyroid shield, possibly lead glasses).

12.1 Literature

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