Proposed Best Practice Checklist:

Imaging Protocols for chILD

Indications

CT scanning is performed to confirm the presence of ILD, because often the paediatrician cannot be sure of this from the CXR; occasionally the CT is daignostic and no further testing (or at least, no biopsy) is needed; to guide the site of the biopsy; and, subject to the limitations below, for follow up.

CT PROTOCOL FOR CHILDREN WITH KNOWN OR SUSPECTED DIFFUSE LUNG DISEASE

The principles in these recommendations are applicable to all modern (post 2005) multi detector CT scanners and where possible parameters specific to a given manufacturers CT machine have been avoided.

Patient Preparation

Special considerations apply to neonates and very young children, but most children over 3 years of age can comply with the demands of an unenhanced CT of their lungs. A short interaction with the child before the CT allows an opportunity to determine whether the child is able to carry out instructions to breath-hold during the scan; quiet respiration is acceptable if voluntary breath-holding is not possible. Feeding neonates prior to the CT may encourage them to fall asleep during the procedure; otherwise a short-acting sedative such as chloral hydrate may be administered. More rapid onset and short-acting sedatives such of propofol, ketamine or midazolam has also been reported as safe and effective with a low incidence of adverse events. General anaesthesia (GA) is rarely necessary and reserved for non-compliant patients and/or those who are unsuitable for sedation. A suggested protocol for general anaesthesia, which will also allow expiratory films to be obtained, is given as an appendix to this SOP. If either sedation or general anaesthesia is used, then possible effects on image quality (e.g. atelectasis) should be considered.

Patient Positioning

The CT imaging couch is primarily designed for adult use. Younger children must be raised up on extra blankets/sponges to ensure they are optimally positioned in the gantry's isocentre - if too far off the isocentre, the tube current may increase and spatial resolution may decrease. The supine child should be placed feet first into the scanner with their arms extended above their head, in this way parents are able to maintain physical contact with their child and reassure them during the procedure. Keeping the arms up and away from the chest reduces image artefacts, particularly at the lung apices. It also improves the performance of machines with automatic tube current modulation (ATCM) because the estimated chest diameter (and thus dose) is increased if the arms lie alongside the chest. Patients under general anaesthesia should also ideally be imaged in this position with ventilation tubing positioned away from the chest area. Under GA respiration can be suspended at near total lung capacity (TLC) to optimize imaging of the lung parenchyma.

Basic Imaging Protocol

The preferred initial diagnostic CT imaging protocol is a low-dose thin-slice volumetric acquisition of the entire lung volume with the patient breath-holding at end-inspiration, without the administration of intravenous contrast medium. Specifically, administration of contrast medium will make the assessment of ground glass shadowing almost impossible. Details of recommended acquisition and reconstruction parameters for the topogram/scout-view and subsequent CT of the lungs are given in Tables 1 and 2 respectively.

Although the radiation burden is higher than the traditional 'high resolution' (HRCT) i.e. non-contiguous (or interspaced) sequential sections protocol used for assessing interstitial lung disease, the obvious advantage of a volumetric acquisition is that it allows examination of all of the lungs, thus minimising underestimation of subtle or localised abnormalities.

Acquisition times for volumetric scanning are short, and no longer than a single breath hold (again, shallow breathing is acceptable if the child is uncooperative or young) and hence easier to perform than repeated non-contiguous data acquisition, which requires more skill and patience on the part of technologists/radiographers.

Image data are reconstructed on a high spatial resolution (lung or bony) algorithm for optimal lung parenchyma display and (where deemed necessary) on a medium-soft algorithm to demonstrate mediastinal structures.

If a mixed airways and interstitial process is suspected (for example subacute hypersensitivity pneumonitis) a limited interspaced 3-slice end-expiratory CT acquisition may be undertaken to demonstrate the presence of lobular air-trapping, although this should not be regarded as a routine of obligatory addition in patients with diffuse lung disease. An alternative technique for patients unable to breath-hold, is to place the individual in the decubitus position, with two spaced slices taken in both right and left decubitus positions, Table 3. The dependent lung behaves as if in a state of expiration, whilst the non-dependent lung is in inspiration.

The near isotropic resolution of modern CT scanners means that high quality image reformats in any viewing plane are possible; in addition various post-processing procedures such as minimum intensity (MinIP) and maximum intensity projections (MaxIP) may aid diagnostic interpretation.

In cases in which follow-up CT is felt justifiable, for example to monitor disease progression, a non-contiguous sequential HRCT protocol should be followed, essentially sampling the lungs (apices to lung base) at end-inspiration using 1mm slice width with a 10mm (in larger children 15 or 20 mm) inter-slice gap, Table 4.

Optimising Exposure Parameters

Because CT carries a relatively high radiation burden to the patient, every effort must be made to limit the radiation dose and thus minimise risks of harm to children who are particularly susceptible. Optimisation of the imaging parameters is mandatory, with protocols tailored to take into account the patient's age and weight. This can be done by having weight-specific protocols as given in Tables 2-4. Particular care should be taken to limit the CT examination only to the area of interest, so that radiosensitive organs are not inadvertently included.

It is now standard practice to use a relatively low kVp (80 - 100kVp) when imaging children, without detriment to image quality. The mAs can be set manually or the ATCM image quality indicator can be set instead. ATCM features that adapt the tube current to the body size and attenuation properties along the cranio-caudal axis are desirable. The effectiveness of ATCM features that adjust the tube current with projection angle is reduced in younger children due to their more spherical (and less elliptical) body shape.

Weight-specific scan protocols with manual mAs can be configured by adjusting the mAs to obtain the target CTDIvol values in Tables 2-4. Configuring ATCM protocols is more complex but can be approached as follows:

(1) Initially configure the weight-specific scan protocols using the manufacturer's suggested values for the image quality indicator (quality reference mAs, noise index etc.)
(2) When scanning patients using these protocols, note the predicted CTDIvol after the topogram/scout view and adjust the image quality indicator until the target CTDIvol is achieved. Make a note of the new value. Proceed with the scan.
(3) Use the scan technique described in (2) for a few patients (about 5) in each weight range. Taking an average of the post-adjustment image quality indicators will provide best-estimates of what the image quality indicator values should be in the various scan protocols.
(4) Re-configure the scan protocols by setting the image noise indicators to the average values obtained from the exercise above.
(5) Scan patients as normal.

Scan pitch is also important in spiral acquisition: a pitch greater than 1 decreases examination time, which is beneficial when imaging younger children, particularly as a means of reducing motion and respiratory artefact. However, with increasing pitch (in an attempt to scan more rapidly), the overscan at the beginning and end of the scan increases, and the ATCM may be less able to respond to changes in attenuation along the cranio-caudal axis, particularly in scanners with x-ray beam collimations greater than 20 mm. Furthermore, spatial resolution may be compromised through broadening of the CT slices at higher pitches. A pitch of 1 for scanners with x-ray beam collimations of about 20 mm, and a pitch of less than 1 for scanners with x-ray beam collimations greater than 20 mm, is a good compromise.

Table 1. Topogram / scout view imaging parameter

Scan Parameter	80kV, 20mA
Scan Direction	Cranial-Caudal
Tube Position	Under Table

Table 2. Volumetric Chest CT Imaging Protocol

Scan Mode	Helical	
Scan Parameter	kV	target CTDIvol mGy (IEC Body dosimetry phantom)
Under 9kg	80	0.9
10 - 15kg	100	1.0
16 - 25kg	100	1.3
26 - 35kg	100	1.4
36 - 45kg	100	1.6
Over 46kg	100	1.8
Dose Modulation	On	
Tube Rotation	0.5sec	
X-ray Collimation	20 mm or more at 0.5 or 0.6 mm slice collimation	
Coverage	Apices to lung bases	
Scan Pitch	1 or less for x-ray collimations greater than 20 mm	
Recon Slice Width	1mm	
Recon Kernel	1st recon - sharp (e.g. B60 for Siemens) 2nd recon – medium-soft (e.g. B30 for Siemens)	
Window Width/Level	1st recon – high-resolution lung parenchymal setting 2nd recon – mediastinal setting	
Post-Processing	3mm coronal MPR, sharp kernel (e.g. B60 for Siemens), lung parenchymal setting Optional: axial and coronal MinIPs	

***Table 3. Expiratory HRCT Imaging Protocol (NB ONLY USED IF SMALL AIRWAYS DISEASE ALSO SUSPECTED)**

Scan Mode	Sequence
Scan Parameter	kV target CTDIvol mGy (IEC Body dosimetry phantom)
1 - 25kg	100 0.06
26 - 35kg	100 0.08
36 - 45kg	100 0.09
Over 46kg	100 0.10
Dose Modulation	On
Tube Rotation	0.5sec
X-ray Collimation	~1mm (e.g. 2 x 1mm for Siemens)
Coverage	Ability to breath-hold - 3 evenly spaced slices at the apices, carina and lung bases Inability to breath-hold - 2 slices each side with patient in R & L decubitus position
Table Feed	25mm-35mm dependent on size of child
Recon Slice Width	1mm
Recon Kernel	1st recon - sharp (e.g. B60 for Siemens), on lung parenchymal setting 2nd recon - medium-soft (e.g. B30 for Siemens), on mediastinal setting
Window Width/Level	1st recon - high-resolution lung parenchymal setting 2nd recon - mediastinal setting

***Table 4. Inspiratory interspaced 'HRCT' Imaging Protocol (for follow-up studies)**

Scan Mode	Sequence
Scan Parameter	kV target CTDIvol mGy (IEC Body dosimetry phantom)
1 - 25kg	100 0.17
26 - 35kg	100 0.20
36 - 45kg	100 0.25
Over 46kg	100 0.35
Dose Modulation	On
Tube Rotation	0.5sec
X-ray Collimation	~1mm (e.g. 2 x 1mm for Siemens)
Coverage	Apices to lung bases
Table Feed	10mm (15 or 20mm in older taller patients)
Recon Slice Width	1mm
Recon Kernel	1st recon - sharp (e.g. B60 for Siemens), on lung parenchymal setting 2nd recon - medium-soft (e.g. B30 for Siemens), on mediastinal setting
Window Width/Level	1st recon - high-resolution lung parenchymal setting 2nd recon - mediastinal setting

RECOMMENDATIONS:

We should report and audit for all centres:

1. Radiation dose used; the figures here may need to be exceeded for various reasons, but this should be the exception.
2. Diagnostic quality of the scans. Clearly we all need to balance radiation and diagnostic quality, but we also need to audit our performance

Appendix. Protocol for general anaesthetic HRCT scans. This has been used succesfully in our London Cystic Fibrosis Collaborative multicentre study.

ANAESTHETIST'S and RADIOGRAPHER'S GUIDELINES

The DAY before CT scan

- Senior clinican at each centre to ensure that anaesthetist and assistants, and radiographer responsible for the procedure realise that this is a CT with a special protocol that must be adhered to from the point of anaesthetics, ventilatory pattern and scanning parameters.
- To read the respective research protocols (anaesthetics and scanning protocols) prior to the day of the procedure.
- Ensure that intercom fully functional in CT suite

Preparation before patient's arrival (At least 15 minutes before patient's arrival)

- Anaesthetist, radiographer, any assistants and senior clinican meet to discuss execution of the protocol and to clarify instructions/ communication about acquiring topogram, inspiratory spiral and expiratory scans.
- Ensure that handheld manometer gauge and anaesthetic circuit set up as per protocol and working. (fresh circuit per subject)
- Ensure that intercom between CT scan and control room is working and at adequate volume. It is VITAL that anaesthetist and radiographer can hear each other clearly, as communication MUST be verbally expressed and **not through automated CT machine**.

THE DAY OF THE SCAN

- Unless contra-indicated, induction of anaesthesia will generally be gaseous using oxygen and nitrous oxide and sevoflurane.
- Atracurium (0.5mg/kg) administered IV as a muscle relaxant, paralysis being maintained throughout the CT and BAL.
- The child will be intubated with an appropriately sized endotracheal tube to ensure minimal leak at 35 cmH_2O and sufficient calibre to pass a 2.8mm bronchoscope.
- Anaesthesia will be maintained for the CT scan with sevoflurane oxygen and air (FiO_2 0.3) and patient ventilated to maintain appropriate end tidal CO_2 (4.5-5kPa) with 5 cmH_20 PEEP, using **handheld pressure gauge/manometer (essential equipment to take to CT– you cannot rely on ventilator settings)**
- During initial mask bagging, there is a tendency for air to enter stomach which may distort images. Pass NG tube and apply suction to reduce any gastric distension PRIOR to initial topogram.

- Baseline ventilatory pattern via anaesthetic machine: pressure controlled IPPV,
    - Respiratory rate 20 bpm
    - I:E ratio 1:2
    - VT 8-10ml/kg
    - PEEP: 5 cmH_2O

PROCEDURE

- Radiographer will adjust scan parameters and once ready for topogram will say **'READY FOR TOPOGRAM'.**

- The anaesthetist will then ensure **patient breath-hold on full inspiration at 25 cmH_2O** and say **'GO FOR TOPOGRAM'** until instructed to release by radiographer who will say **'FINISHED'**.

- Radiographer will adjust scan parameters for inspiratory and expiratory acquisitions. Once ready, radiographer will say **'START INFLATIONS for INSPIRATORY SCAN'.**

- Anaesthetist will then perform
    - **6 deep slow inflations** to **35-40 cmH_2O** with a **PEEP of 6 cmH_2O** to reverse any anaesthetic related atelectasis (anaesthetist will count up from **1 to 6**), followed by
    - **4 deep slow inflations** to **25cmH_2O** with a **PEEP of 5 cmH_2O** to provide standard lung volume history (anaesthetist will count down from **4 to 1** and then **say GO** at the final inflation (on the count of 1) **to 25cmH_2O.**

- During the inspiratory scan, the child's lungs will be held in inspiration for **~6s at 25 cmH_2O,** until radiographer instructs **'FINISHED INSPIRATORY SCAN'**.

- Anaesthetist will then release BAG completely to allow **passive expiration to relaxed end expiratory volume (ZERO PEEP).**

- Once lung deflation complete**;** Anaesthetist instructs radiographer by saying **'GO FOR EXPIRATION'** *(In-built 6s delay before scan commences ensures stable end expiratory level)*
- Radiographer will inform anaesthetist when complete and **normal ventilatory support can resume**.