Contents

CHAPTER 1

Introduction to CT of the Thorax: Chest CT Techniques

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Spiral (helical) computed tomography (CT) allows the entire chest to be imaged in a few seconds or less (i.e., during a single breath hold), with volumetric acquisition of scan data. Two- and three-dimensional reformations may be performed if desired. Because scanning is rapid, contrast agents can be injected quickly, excellent vascular opacification can be achieved, and reduced volumes of contrast agent can be used.

Multidetector CT (MDCT) scanners have multiple parallel rows of X-ray detectors (an ever-increasing number, now exceeding 250 in some scanners, and capable of reconstructing more than 500 slices at a time). With MDCT, each of the detector rows records data independently as the gantry rotates; consequently, a volume of the patient (e.g., up to 16 cm along the longitudinal axis, or *z*-axis, with a 256-detector scanner) is imaged with each gantry rotation. With large-area detector scanners, scanning of a volume may be performed without table motion; this is most useful for cardiac imaging. The gantry rotation time is 0.5 seconds or less.

SPIRAL CHEST CT: GENERAL PRINCIPLES

The specific protocols used for chest CT depend on the scanner used, the scanner manufacturer, and the reason for the study. However, several general principles apply to all chest scans (Table 1.1).

Scan Levels

Chest CT is usually performed from a level just above the lung apices (near the suprasternal notch) to the level of the posterior costophrenic angles; these scans also encompass the diaphragm and the upper abdomen. The distance (or volume) needed to cover the thorax (usually 25–30 cm) is determined by a preliminary projection scan (e.g., a "scout view").

Patient Position

Routinely, patients are scanned supine. Prone scans may be obtained for high-resolution CT (HRCT) or to assess movement of pleural fluid collections. The patient may also be positioned prone for biopsy of posterior lung lesions or drainage of pleural fluid collections.

Lung Volume

Scans are routinely obtained after a full inspiration (i.e., at total lung capacity) and during suspended respiration. Postexpiratory scans may be performed in some cases (particularly on HRCT) to assess air trapping.

Detector Row and Slice Thickness

Scan data are usually acquired with the thinnest detector width available on the scanner (detector rows on most scanners range from 0.25 to 0.625 mm), and the reconstructed slice thickness used for scan interpretation is determined by the indication for the scan. For example, if data are recorded with 0.625-mm detectors, slices can be reconstructed at any thickness from 0.625 to 5 mm for viewing. Thin slices are required for some specific indications, whereas thicker slices are quicker to interpret and do not occupy as much memory when they are stored.

Most chest scans are reconstructed with a 1- to 1.25-mm thickness. When one is viewing a study reconstructed with 2.5- or 5-mm-thick slices, if the scan data were collected using thinner detectors, and if the scan data are still available (they are usually preserved on the scanner disk for a day or two), you can have thinner slices reconstructed at a later time.

Usually slices are reconstructed at an interval equal to the slice thickness (e.g., 1.25 mm) to provide a volumetric data set. On occasion, scans are reconstructed at overlapping levels (e.g., 1.25-mm slices reconstructed at 0.625-mm intervals), although this is not generally necessary.

TABLE 1.1
Chest CT: General Principles

Scan levels: Lung apices to the posterior costophrenic angles
Patient position: Supine; prone scans sometimes used for diagnosis of lung disease of pleural effusions
Lung volume: Full inspiration, single breath hold; expiratory scans sometimes used to diagnose air trapping or bronchial abnormalities
Gantry rotation time 0.5 seconds or less in most instances
Scan duration: 2.5 seconds or less for the thorax, with use of multiple-detector CT and fast scanning
Detector width: Usually the thinnest detectors (e.g., 0.625 mm or less) for image acquisition
Pitch (table excursion): Depends on tolerable image noise; increased if noise is OK; decreased if there is a desire for high resolution
Reconstruction algorithm: High-resolution algorithm used for most studies; standard or soft-tissue algorithm usually used for vascular studies
Two- or three-dimensional reconstructions: Not routine; occasionally useful for lung, airway, or vascular studies
Contrast agents: Intravenous contrast agent injection in some cases; oral contrast agents only for gastrointestinal abnormalities

Pitch (Table Excursion)

The term *pitch* refers to the distance the table travels during a complete gantry rotation divided by the width of all the detectors used (e.g., table excursion/detector width × number of detector rows). With MDCT, pitch usually ranges from 1 to 2. The higher the pitch, the faster the scan, but images are generally noisier, spatial resolution is reduced somewhat, and the effective slice thickness (the thickness of the patient that is actually imaged) is increased.

Keep in mind that with the spiral technique the actual thickness of the slice you view (i.e., "effective slice thickness") may be greater than the slice thickness you select (e.g., 1.25 mm), depending on the pitch or table excursion during gantry rotation; the greater the pitch, the greater the effective slice thickness. Thus there is a trade-off; with a higher pitch, the study is quicker but the scans are not quite as good.

Scan Duration

MDCT of the chest can be easily performed during a single breath hold (2.5 seconds or less), generally avoiding respiratory motion artifacts, except in very dyspneic or uncooperative patients.

Reconstruction Algorithm

Once the scans have been performed, the scan data are reconstructed using an algorithm that determines some characteristics of the resulting image. For routine chest imaging, a *high-resolution algorithm* is often used to optimize detail, but this makes the image somewhat noisy in appearance. A standard or *soft-tissue algorithm*, which produces a smoother image, is better for assessing thoracic vascular structures (e.g., studies performed for diagnosis of pulmonary embolism, aneurysm, or aortic dissection) but is not optimal for other chest imaging. This algorithm is often used for abdominal imaging.

Two- and Three-Dimensional Reconstruction

Because the scan data are acquired continuously and volumetrically by spiral CT, scans may be reconstructed in any plane desired. A variety of display techniques have been used for imaging the thorax. These include multiplanar reconstructions, three-dimensional shaded surface display or volume rendering from an external perspective, or shaded surface or volume rendering from an internal (i.e., endoluminal) perspective, also known as *virtual bronchoscopy*.

Multiplanar, two-dimensional reconstructions offer the advantage of being quickly performed and are sufficient for diagnosis in most cases in which a reformation is considered desirable. Subsequent chapters provide a number of examples of two-dimensional reconstructions. Three-dimensional techniques, such as shaded surface display and volume rendering, can be valuable in selected cases, but they are time-consuming and require operator experience. These techniques are not commonly used in day-to-day clinical chest imaging.

Maximum- or minimum-intensity projection images representing a slab of three-dimensional data reconstructed from a volumetric data set may sometimes be useful in imaging pulmonary, airway, or vascular abnormalities.

Window Settings

For chest CT, scans must be viewed with at least three different window settings. Scans are usually viewed with a workstation having preset windows available. The presets used when one is reading chest CT scans are generally termed *lung*, *soft-tissue* (or *mediastinal*), and *bone* windows, names that also describe their primary use. These preset windows are often adjusted by the viewer during scan interpretation to optimize visibility of certain structures or abnormalities of interest.

Lung windows typically have a window mean of approximately -600 to -700 Hounsfield units (HU) and a window width of 1000 to 1500 HU. Lung windows best demonstrate lung anatomy and disease, contrasting soft-tissue structures with surrounding air-filled lung parenchyma.

Mediastinal or *soft-tissue windows* (window mean 20–40 HU; window width 450–500 HU) demonstrate soft-tissue anatomy in the mediastinum and in other areas of the thorax, allowing the differentiation of fat, fluid, tissue, calcium, and contrast-opacified vessels. This window is also of value in providing information about consolidated lung, the hila, pleural disease, and structures of the chest wall. Subsequent chapters discuss more specific uses of these two windows. In the assessment of vascular structures (e.g., for pulmonary embolism or dissection diagnosis), a wider window or higher window mean than that used for a routine mediastinal window is often selected by the radiologist to better see detail within the dense contrast column.

Bone windows typically have a window mean of approximately 300 to 500 HU and a window width of 2000 HU. They best demonstrate skeletal structures or very dense objects. This window is sometimes valuable in looking at densely opacified vascular structures.

SPIRAL CHEST CT: PROTOCOLS

In most patients, chest CT is performed with a routine protocol. This technique is designed to provide useful information about the lung, mediastinum, hila, pleura, and chest wall. It is valuable in the diagnosis of a variety of diseases and types of abnormalities. Modified CT techniques are used in specific clinical settings or to look for specific abnormalities (e.g., pulmonary embolism, aortic dissection, and diffuse lung disease). Subsequent chapters provide detailed reviews of some specific protocols.

With current scanners having a large number of detector rows (e.g., 128), protocols for evaluation of different types of thoracic abnormalities have become similar, because scanning with thin slices and with excellent contrast opacification can easily be obtained during a single breath hold regardless of why the scan is being done. A general understanding of the principles involved in obtaining CT scans for specific indications is much more important than knowing detailed specific protocols because these differ with different scanners and manufacturers, and among different institutions.

Use of Contrast Agents

Chest CT can be performed with or without the administration of an intravenous contrast agent, depending on the indication for the study. Scans obtained to rule out pulmonary metastases or to assess lung disease, generally do not require the use of contrast agent. Contrast agent should be used in patients with suspected hilar, mediastinal, or pleural abnormalities and in patients with possible vascular abnormalities. If you are unsure of the indication for the scan, the use of a contrast agent is generally appropriate.

With MDCT, injection of contrast agent at 3 to 5 mL per second, 10 to 30 seconds before scanning begins and for the duration of the scan series, provides excellent opacification of vascular structures. For routine indications, injection of contrast agent at 3 mL per second is generally sufficient. When a vascular abnormality is suspected, injection at 5 mL per second is usually used. The rate of contrast agent injection and the scan delay (the time between the start of contrast agent injection and the start of scanning) differ depending on the reason for the study.

Scanning is begun when the vessels of interest are opacified. For pulmonary embolism diagnosis, the pulmonary arteries need to be opacified; this usually requires a 10- to 15-second delay, although timing the scan to the aorta or left atrium may be beneficial. For diagnosis of aortic abnormalities, a delay of usually 20 to 30 seconds is needed. The delay differs in individual patients according to a number of factors. Timing the scan delay is usually done with a timing bolus or software available on the scanner, which shows vascular opacification during the injection, and begins scanning when contrast agent appears in the target vessel. The use of an oral contrast agent for opacification of the esophagus and gastrointestinal tract is not necessary unless a specific gastrointestinal (i.e., esophageal) abnormality is suspected.

Routine Chest CT

With an MDCT scanner, I routinely scan the chest with 0.625-mm detectors, with reconstruction of 1.25-mm slices at 1.25-mm intervals. This allows the entire thorax to be scanned in 2.5 seconds or less. Depending on the indication for the study, a high-resolution algorithm or smooth algorithm may be chosen for image reconstruction, and intravenous or oral contrast agents may be used (see earlier). Generally speaking, with the exception of vascular imaging protocols, a high-resolution reconstruction algorithm will be chosen for reconstruction of most chest CT studies. This routine protocol is used for evaluation in most patients not being assessed for a specific vascular abnormality, such as pulmonary embolism or possible aortic disease, or in patients being evaluated for a diffuse lung disease, which would require a high-resolution CT protocol.

Vascular Imaging Protocols

In some patients, chest CT is performed primarily for the diagnosis of a vascular abnormality suspected on the basis of clinical symptoms or radiographic findings. Common thoracic vascular abnormalities assessed with CT include pulmonary embolism, aortic dissection or aneurysm, and traumatic aortic rupture. Although the protocols for each indication differ among institutions and with different scanners, some general principles apply.

Vascular protocols attempt to optimize the degree of contrast enhancement of the vessels of interest and image resolution, while keeping the length of breath hold and the amount of contrast agent injected at a reasonable value. In general, a relatively smooth reconstruction algorithm is preferred for vascular imaging. Reduced image noise with smooth reconstruction makes it easier to see small filling defects (i.e., pulmonary emboli) and subtle differences in contrast enhancement.

Pulmonary Embolism

For the diagnosis of pulmonary embolism by MDCT, slices 1.25 mm thick at 1.25-mm intervals are sufficient for diagnosis, although scanning is usually performed with the thinnest detectors available (e.g., 0.625 mm). A smooth reconstruction algorithm is generally used. Intravenous contrast agent is injected rapidly (e.g., 5 mL per second). Scanning is begun when the scanner shows the pulmonary arteries or left atrium to be opacified. The delay between the start of contrast agent injection and scanning differs, but it averages about 10 to 15 seconds if pulmonary artery opacification is desired and is somewhat longer for opacification of the left atrium. In large patients, scan noise may make interpretation difficult. In such patients, reconstructing slices 2.5 mm thick may reduce noise and increase accuracy.

Aortic Disease

Aortic abnormalities assessed by CT include dissection, aneurysm, intramural hematoma, penetrating ulcer, and traumatic aortic rupture. A scan series through the thorax with relatively thick (2.5- or 5-mm) slices often precedes contrast agent injection (to look for a high-attenuation intramural hematoma; see Chapter 3). If only the thoracic aorta is being examined, scans through the thorax may be obtained with a protocol similar to that used for pulmonary embolism diagnosis (1.25-mm slices reconstructed at 1.25-mm intervals). Intravenous contrast agent is injected rapidly (e.g., 5 mL per second), and scanning is begun when the scanner shows the left atrium or aorta to be opacified. The scan delay may range from 15 to 30 seconds, depending on the patient. If imaging of the abdominal aorta is also required (e.g., for aortic dissection), scans continue through the abdomen. Quiet breathing during the abdominal portion of the scan is usually allowed if the patient cannot hold his or her breath for the duration of the study.

High-Resolution Lung CT

HRCT is used to diagnose diffuse lung diseases, emphysema, bronchiectasis, and some focal lung lesions (e.g., a solitary nodule). HRCT requires thin slices (e.g., 0.625–1.25 mm) and image reconstruction with a sharp (high-resolution) algorithm, which reduces image smoothing and increases spatial resolution. Although use of a sharp algorithm also increases image noise, this is not usually a problem in the interpretation of lung images. Injection of contrast agent is not necessary for HRCT but may be used on occasion if pulmonary embolism is also a consideration.

Scans performed with the patient supine and prone, and following expiration, are often obtained, at least for the patient's initial examination. *Prone scans* are used to detect subtle posterior lung abnormalities; *expiratory scans* are used to detect air trapping because of airway obstruction.

HRCT can be performed in three different ways:

- *Spaced axial imaging.* Thin slices (e.g., 0.625–1.25 mm) are performed at spaced intervals (e.g., 1–2 cm) without table movement to optimize spatial resolution. Because of the spaced images, the radiation dose is reduced.
- *Volumetric HRCT* using the spiral technique, thin detectors, and 1- to 1.25-mm slice thickness reconstruction. This results in an increased radiation dose and slightly decreased resolution, but the entire thorax is imaged and two- or three-dimensional reconstruction and assessment of other abnormalities (e.g., pulmonary embolism) is also possible. If desired, the scans can be reconstructed with both a high-resolution algorithm (for diagnosis of lung abnormalities) and a smooth algorithm (for diagnosis of vascular abnormalities).
- *Combined volumetric and axial imaging.* In some patients, volumetric imaging is obtained for supine scans, with spaced axial imaging for prone and expiratory images. This optimizes the volume imaged, but with a reduced radiation dose.

Dynamic CT Techniques

The term *dynamic CT* means that a number of scans are performed in sequence. Because spiral scanning is continuous, it is a dynamic technique, but dynamic scanning can also be performed without a spiral technique (i.e., without table and patient motion during the acquisition of scans). Dynamic scanning may be performed at a single level during expiration to detect air trapping or to assess tracheal or bronchial collapse in patients with tracheomalacia or airway disease. Dynamic scanning may also be performed to assess some vascular abnormalities.

Low-Dose CT

Reducing the radiation dose is desirable whenever possible, but generally results in decreased image quality because of increased noise. The term *low-dose CT* usually implies the use of a reduced tube current (milliamperes) during the scan. Low-dose chest CT is usually used in children, for screening of patients (i.e., lung cancer screening), or if multiple follow-up examinations will be necessary in a given patient.

With current MDCT scanners, the tube current can be varied or *modulated* at different levels as the patient is scanned on the basis of the chest wall thickness or amount of soft tissue within the volume being scanned. Because the lungs are not very dense, not as much radiation is needed when the lungs (instead of the shoulders or liver) are being scanned. This technique can significantly reduce the tube current and patient dose, without much loss in scan quality, and is usually used for routine studies. A fixed, higher tube current is sometimes used when high resolution and detail is needed. *Iterative reconstruction* is another technique commonly used to reduce the radiation dose.

RADIATION DOSE WITH CHEST CT

Although the patient risk from radiation exposure during diagnostic CT is small and difficult to determine, medical radiation does result in a finite risk. In clinical practice the patient's potential benefits from a CT study need to be balanced against the small radiation risk. In general, if the study has well-defined clinical utility, it is indicated. Nonetheless, it is important for the radiologist to reduce radiation exposure during diagnostic CT, as long as important diagnostic information is not compromised as a result.

Radiation dose and the associated risk to the patient can be calculated by different methods and measurements, none of which are ideal or necessarily predictive of outcome. The calculation most typically used is effective dose (measured in sieverts or more typically millisieverts), which is determined by summing the absorbed doses to individual organs weighted for their radiation sensitivity. However, because an accurate measurement of all organ doses is difficult to obtain during a clinical examination, as are the risk coefficients specific to age, sex, and the organ being irradiated, the estimated dose is calculated for an idealized 70-kg, 30-year-old patient. Although limited in accuracy and predictive value, the effective dose expressed in millisieverts is the most widely used method for quantification of the radiation dose and comparison of radiologic procedures. Approximate doses for background radiation and thoracic imaging procedures are listed in Table 1.2.

TABLE 1.2
Radiation Dose for Chest CT Protocols

	Radiation Dose (mSv)
Normal yearly background radiation	2.5–3.2
Chest radiograph (single view)	0.05
Routine chest CT (300 mA)	5–7
Routine chest CT (modulated tube current approximately 100–150 mA)	1.5–2
High-resolution CT with volumetric imaging (supine, expiratory; modulated tube current of approximately 100–150 mA)	1.5–2
High-resolution CT with spaced axial images (supine, prone, expiratory)	1
Low-dose volumetric CT (40 mA)	<0.5–1

SUGGESTED READING

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