Imaging of the Thorax

3

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3.1 Introduction

Study of the thorax in children is possible through various diagnostic methods. Each method has its own unique characteristics and an optimal time when it should be carried out to answer a specific clinical question. The first level of investigation is ultrasonography (US) and radiography; the second level is computed tomography (CT) and magnetic resonance imaging (MRI). A diagnostic pathway that provides the lowest radiation dose possible must be used. That is, a pathway that complies with the "as low as reasonably achievable" (ALARA) concept. The need to respect this principle is based on the organ-sensitivity of children and their longer life expectancy, which subjects them to an increased risk of developing a radiation dose-related disease.

3.2 Radiography

Plain radiography of the chest is the most widely used method in different age groups of children (especially in the study of acute illness). Radiography is relatively inexpensive, easy to carry out and is widely available; the information it provides can be processed rapidly; and radiography exposes the patient to a low dose of radiation.

The examination can be conducted in one or two projections in relation to the specific indication. A single radiograph of the chest in supine, anteroposterior or posteroanterior projections is usually sufficient for diagnostic purposes. The collimation of the X-ray beam should be as narrow as possible to avoid exposure of organs and systems that do not need to be imaged. The decision whether the lateral projection is used (especially in younger children) is made by the radiologist.

In children aged >3 years, it may be possible to carry out plain radiography of the chest in the upright position but, if not, the parents can be asked to assist the child to stand correctly (Fig. 3.1). To reduce radiation exposure, protective pads for more radiosensitive tissues (e.g., gonads, breasts) can be used. The chest radiograph allows: evaluation of lung expansion and heart size; study of the mediastinum; positioning of catheters, endotracheal tubes and chest drains (Fig. 3.2).

3.3 US

US was initially used for the quantification and evaluation of pleural effusions. However,

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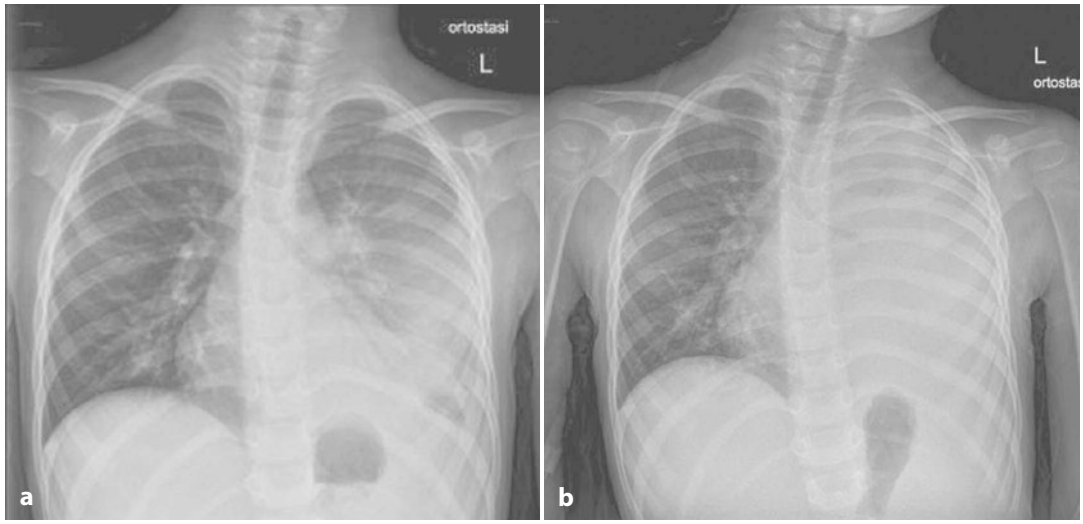

Fig. 3.1 Chest radiograph, AP projection (**a** and **b**). Large left bronchopneumonic focus complicated by pleural effusion

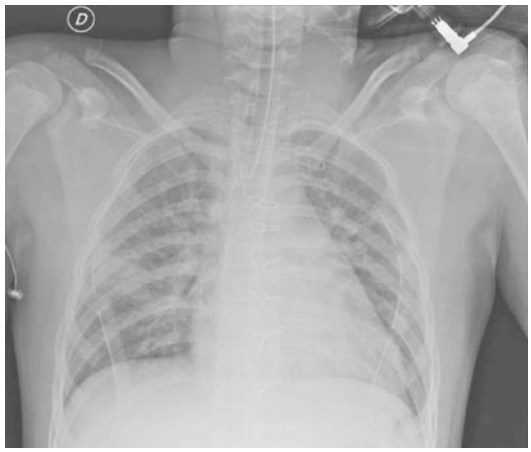

Fig 3.2 Chest radiograph with patient in the supine position showing placement of medical-evaluation devices (central venous catheter, drain)

over time, its use been has been extended to the study of the parenchyma and mediastinum [1, 2]. The procedure is highly operator-dependent, does not use ionizing radiation and, in most cases, does not require sedation. These characteristics are of fundamental importance if using US in children.

Penetration of the ultrasound beam is hampered by bone and air in healthy lungs. Study of parenchymal and mediastinal lesions can be conducted through special "acoustic windows". Furthermore, the low mineralization of bone permits approaches that cannot be used in adults.

The investigation must be carried out after careful evaluation of chest radiographs. This evaluation guides the choice of the most appropriate position for the patient (supine, prone, lateral). The indications for US are for the study of: pneumonia (especially if complicated by pleural effusions (Figs 3.3–3.5)); solid pulmonary lesions; congenital lung malformations; diaphragm profiles; the mediastinum. In addition, thoracentesis and biopsies can be done under US guidance [3]. Color and Doppler procedures (Fig. 3.6), although potentially problematic because of the lack of compliance from young patients, permit evaluation of the vascular structures without the need for intravenous administration of contrast agents. They are very useful as adjuncts to conventional investigations for the study of lung seizures, pulmonary masses and parenchymal masses [3, 4].

3.4 CT

The advent of CT in 1970 by Hounsfield radically changed radiology. In children, introduc-

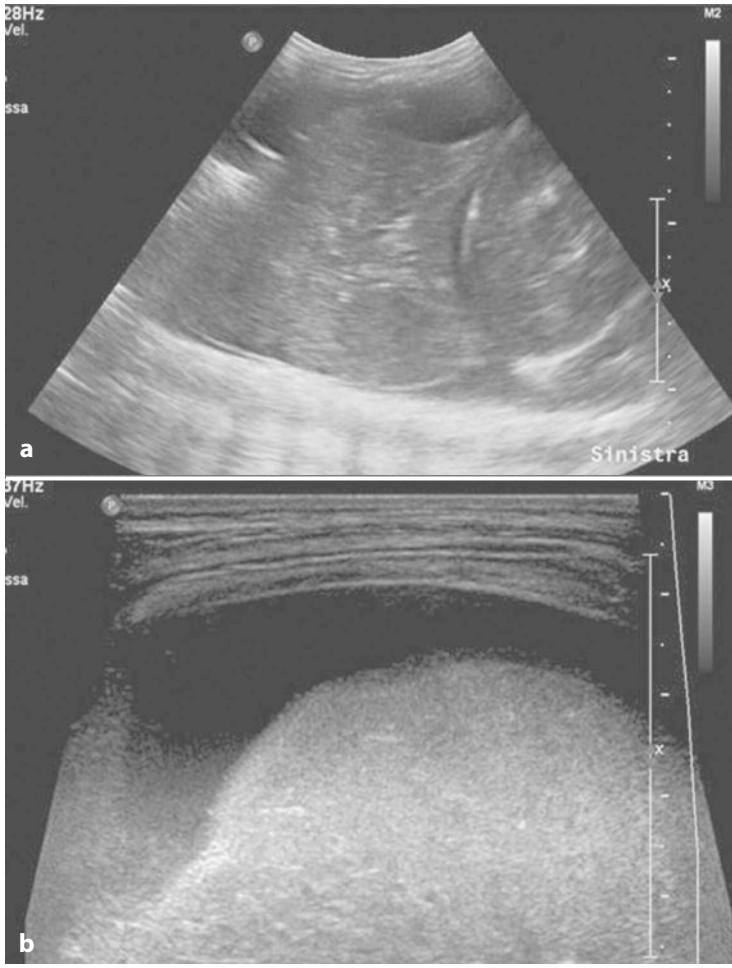

Fig. 3.3 Ultrasound of the lung (**a** and **b**) showing parenchymal hepatization with pleural effusion

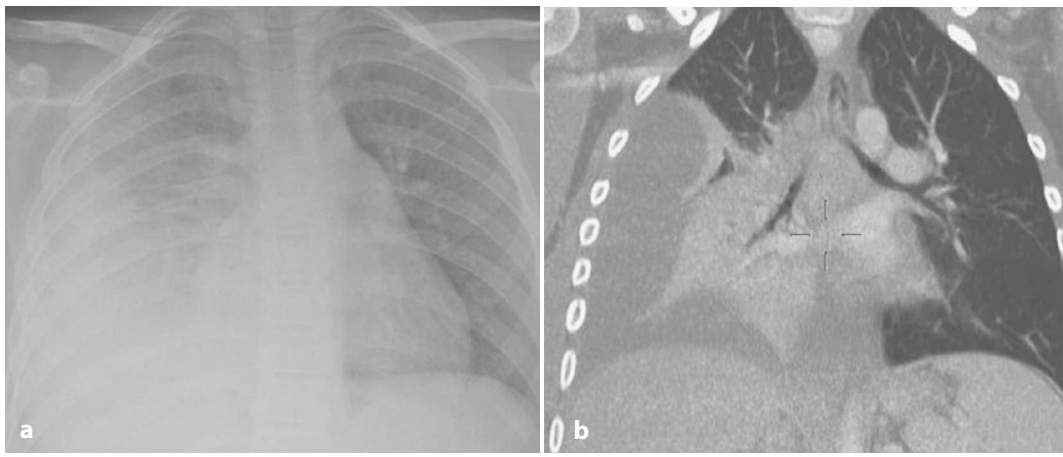

Fig. 3.4 Radiography (**a**) and (**b**) CT of the chest. The right pleural effusion is: organized; along the marginal rib; associated with parenchymal atelectasis

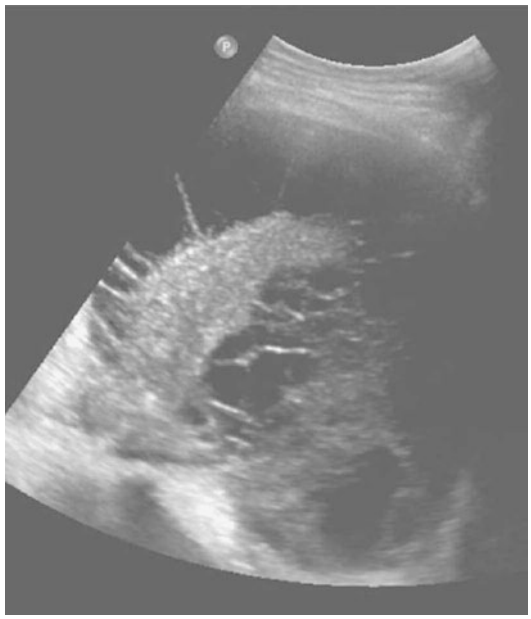

Fig. 3.5 Ultrasound of the lung of the same patient shown in Figure 3.4. Pleural effusion has evolved into empyema with cavities and septa, and is associated with major parenchymal atelectasis

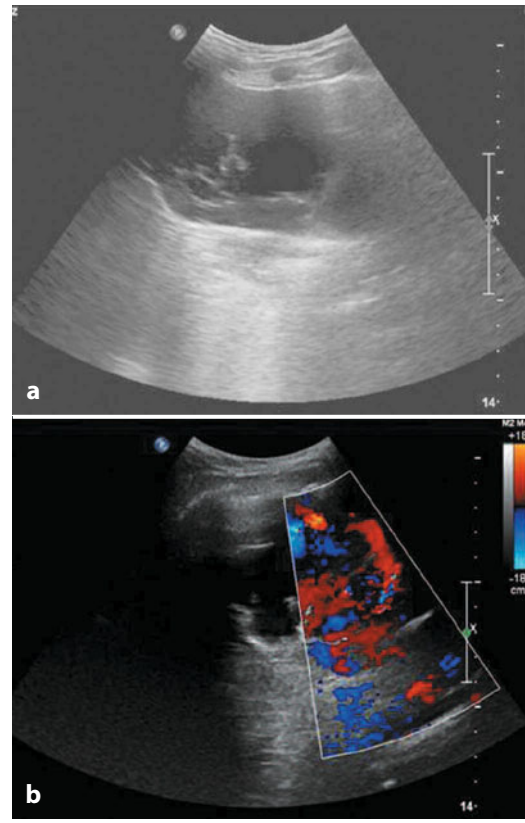

Fig. 3.6 Ultrasound (**a**) and echo-color Doppler (**b**) of the lung showing a mediastinal mass

tion of the spiral method (particularly the subsequent advent of MDCT) has greatly increased the sensitivity and specificity of CT. It has also significantly improved the diagnostic yield as well as extended the indications for use, especially in the study of the chest in pediatric patients.

With respect to spiral CT, MDCT also allows the acquisition of larger volumes in less time and the use of ever-thinner slices to allow multiplanar reconstructions from raw data [5]. These methods allow: study of the airways; evaluation of vascular structures; CT angiography to be undertaken; virtual endoscopy. The diagnostic possibilities are increased because of multiplanar reconstructions and post-processing of data. Reworking of acquired data is another important resource provided by this method. Several types of CT can be afforded, including multiplanar reconstructed (MPR; Figs 3.7–3.9); three-dimensional (3D) shaded surface display (SSD); volume reconstruction (VR); and volume rendering (VR; Fig. 3.10). These subsequent revisions add value to the axial images, allowing more accurate and reliable diagnostic evaluations in a high percentage of cases [6].

The paucity of visceral fat and difficulty in acquiring images marred by motion artifacts makes the acquisition of good-quality images problematic, thereby complicating recognition of normal structures and certain types of diseases. With respect to motion artifacts, subjects aged <3 years are usually sedated, whereas those aged >5 years can undergo CT if made to feel comfortable with verbal assurances and use of toys.

Single acquisition of the thorax should be carried out after the intravenous administration of contrast medium. This administration should be avoided in cases of interstitial disease (in which only high-resolution computed

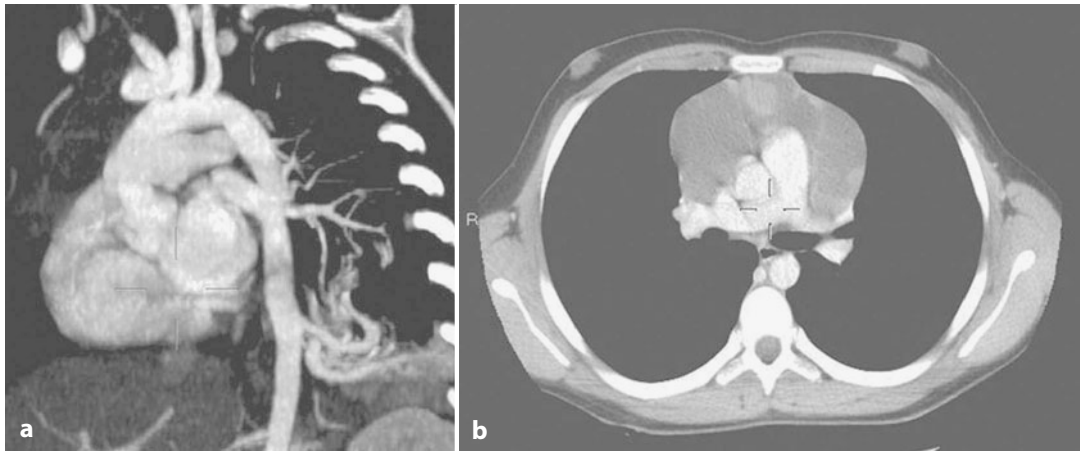

Fig. 3.7 CT: maximum intensity projection (MIP) multiplanar reconstruction (MPR) (sagittal reconstruction) showing pulmonary sequestration (**a**). MIP MPR axial reconstruction showing a thymic mass (**b**)

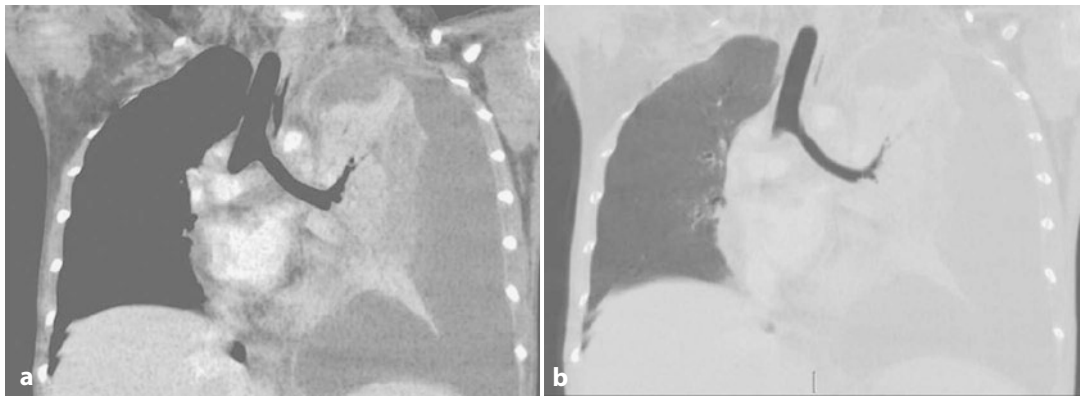

Fig. 3.8 Coronal MIP MPR (**a**) and minimum intensity projection (MinIP) (**b**) showing a focus complicated by a pleural effusion

tomography (HRCT)) should be done) or for studies of malformations of the chest wall (Fig. 3.11) [7]. A non-ionic, organo-iodinated contrast agent at about 2 mL/kg should be employed. Administration of these contrast agents can be slightly more complex than in adult patients due to the wide variability of circulation and caliber of the small vessels of pediatric patients. The injection should ensure even distribution of the contrast agent. Imaging is usually carried out approximately 20–30 s after injection (the first 20 s if the patient is aged <2 years). Image acquisition is in the inspiratory phase in cooperative patients, free-breathing in the non-cooperative. The main disadvantage of CT is the radiation dose to which patients are exposed, which is especially important in children. Hence, before subjecting a patient to CT, one must ascertain if the same information can be obtained without the use of ionizing radiation [8, 9].

One indication for the diagnostic use of contrast-enhanced CT in children is mediastinal/thoracic nodules and masses, particularly those localized in areas that cannot be seen using conventional methods (lung apex; near the diaphragm; adherent to the chest wall; at the level of the central airways). Obtaining reconstructed images with thin overlapping sections allows detection of small lesions and

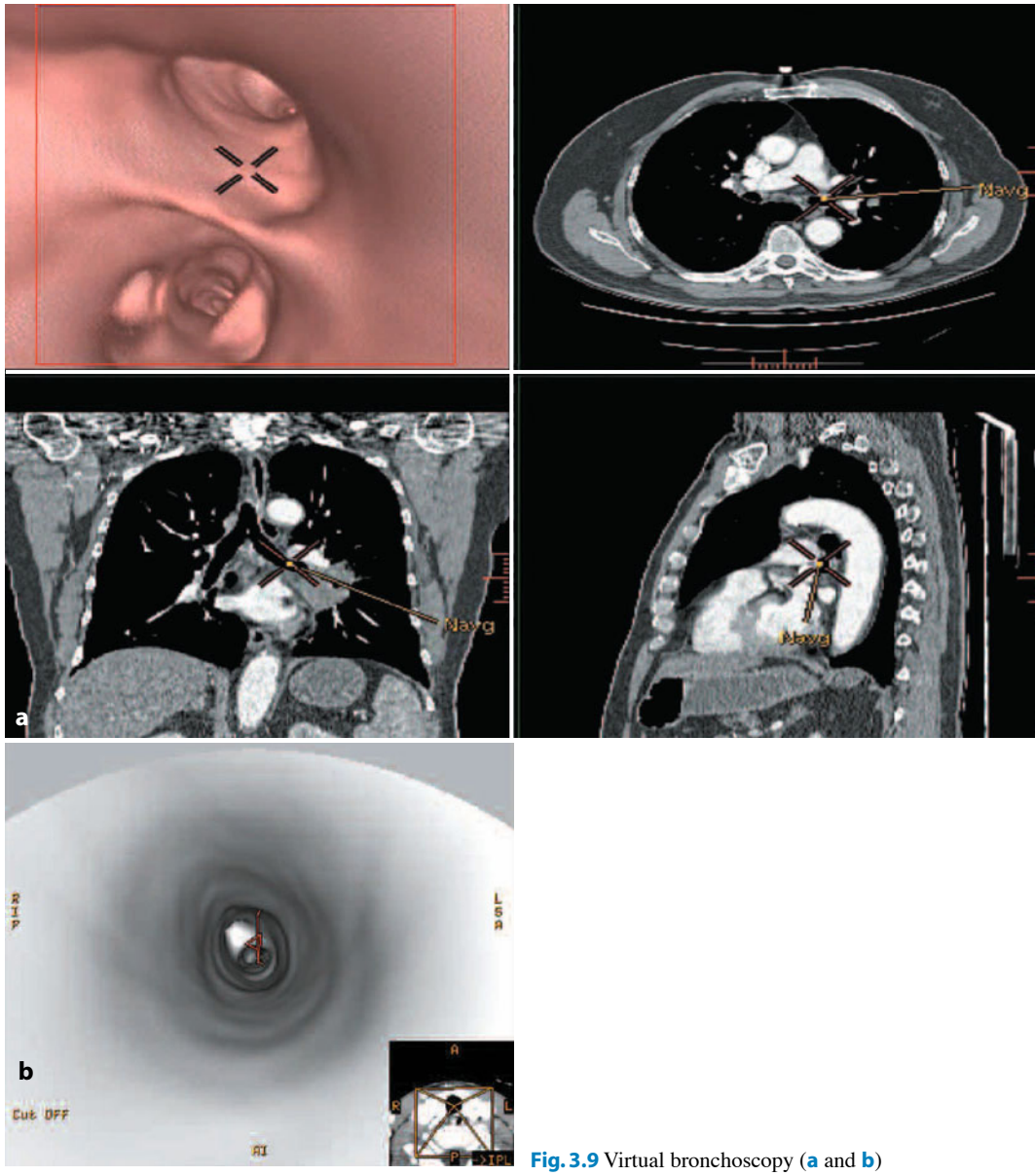

Fig. 3.9 Virtual bronchoscopy (**a** and **b**)

eliminates breathing artifacts. Another important indication is the study and follow-up of tumor lesions. CT permits assessment of the level of infiltration of tissues, vascular structures and airways, resulting in the possibility of better surgical planning and radiotherapy. Also, CT angiography allows the study of vascular malformations (congenital and acquired) (Fig. 3.12). The bolus-tracking technique allows correct synchronization of the time of acquisition of arterial and venous phases [5, 10, 11].

Important anatomical features of surgical interest can also be provided if CT is used to study diaphragmatic hernia (Fig. 3.13) and cystic parenchymal malformations. In studies of congenital diaphragmatic hernia (CDH), partial or complete discontinuity of the diaphragmatic profile can be ascertained, as can abnormal migration of abdominal structures in the chest (which can result in compression of the parenchyma and thus hinder development). The prognosis is strongly related to gestation-

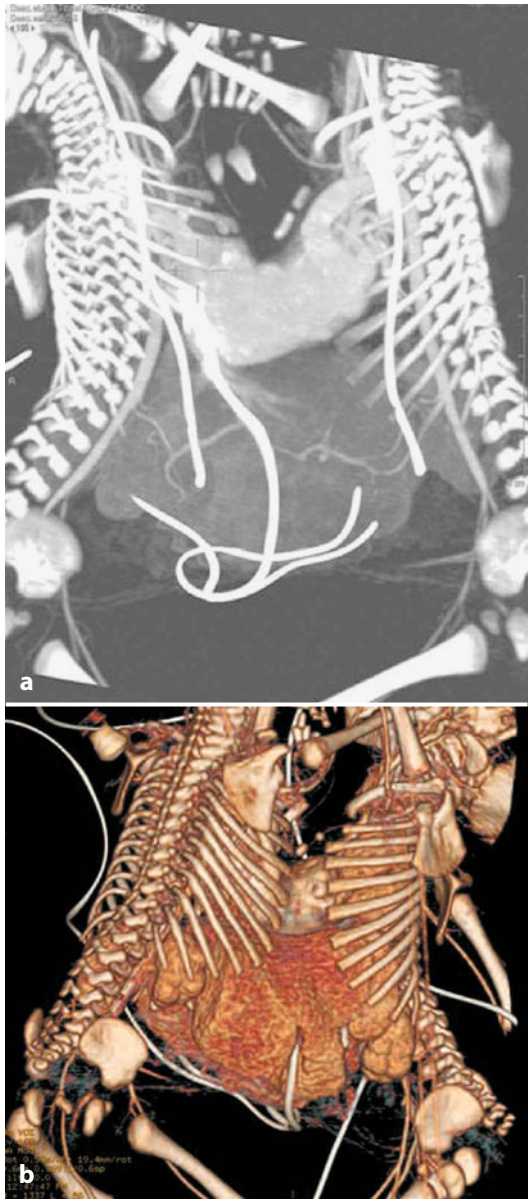

Fig. 3.10 MIP MPR (**a**) and three-dimensional volume rendering (VR) (**b**) showing thoracopagus conjoined twins

al age at onset, so quantification of pulmonary hypoplasia using CT is essential. In fact, anomalies which occur before the 25th week of life are associated with severe developmental abnormalities of the lung that carry a poor prognosis. The most common abnormality is the foramen of Bochdalek, which develops more frequently on the left side.

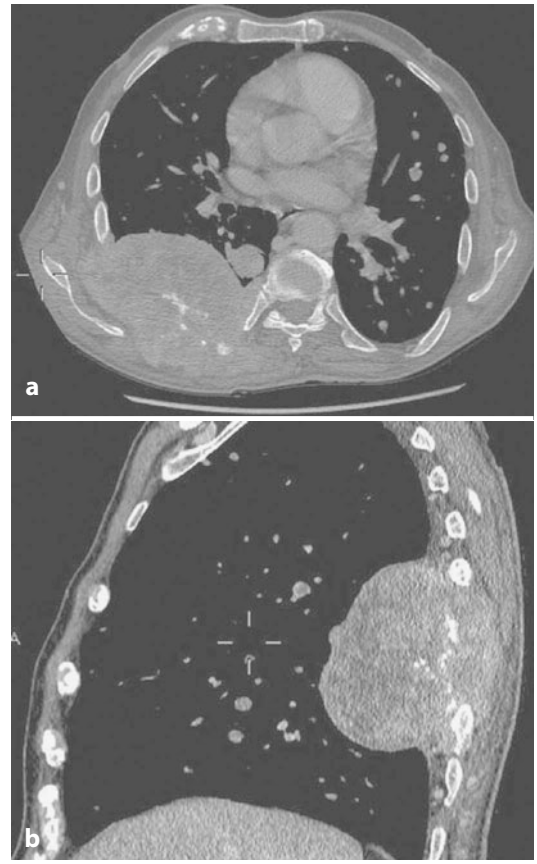

Fig. 3.11 Axial (**a**) and sagittal CT (**b**) showing an expansive formation in the chest wall with rib erosion

CT can be used to study cystic parenchymal malformations. This group of diseases includes: simple congenital thoracic cysts; cysts within the mediastinum and parenchyma (bronchogenic cysts, duplication cysts, pleuropericardical cysts); and adenomatoid cystic disease of complex congenital cystic-pulmonary sequestration (CAM); and pulmonary sequestration [12–15].

The management of simple mediastinal cysts is according to symptoms. All cysts within the lung parenchyma should be considered to be bronchogenic and require surgical treatment. The definitive diagnosis is established by study of the cyst wall; the diagnosis may be more difficult if there are signs of inflammation in the cyst wall. Bronchogenic cysts are, in general: solitary and spherical in shape; surrounded by a thin layer of bronchial epithelium; and com-

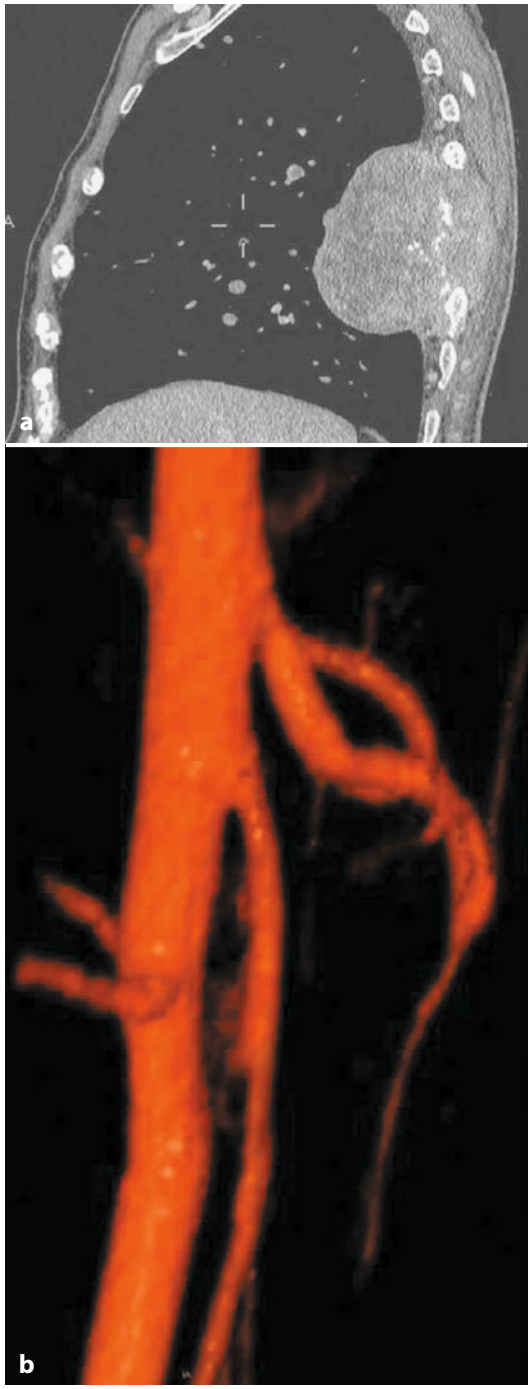

Fig. 3.12 MIP (sagittal reconstruction) (**a**) and VR reconstruction (**b**) showing the arteries in the abdominal aorta and their branches

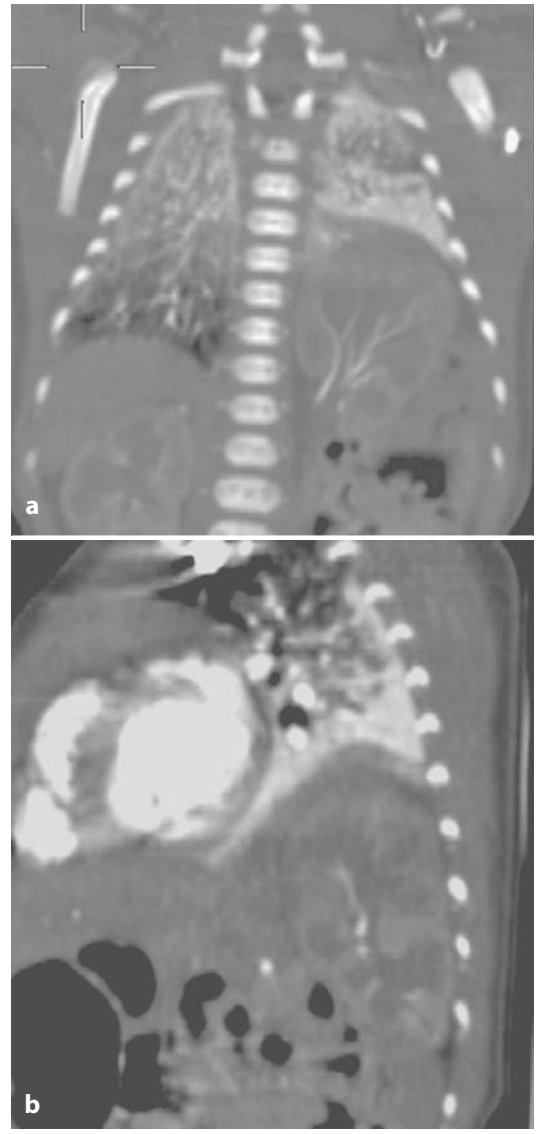

Fig. 3.13 Coronal (**a**) and sagittal MPR (**b**) showing a left diaphragmatic hernia

prise viscous, mucoid, hemorrhagic or aqueous content. They may contain calcium, internally or at the level of the wall, or are completely calcified and in communication with the airway. Sometimes bronchogenic cysts can be in association with other malformations such as pulmonary sequestration, lobar emphysema or bronchial atresia. The panels may also show moderate enhancement after administration of contrast agent [16]. Mediastinal cysts show

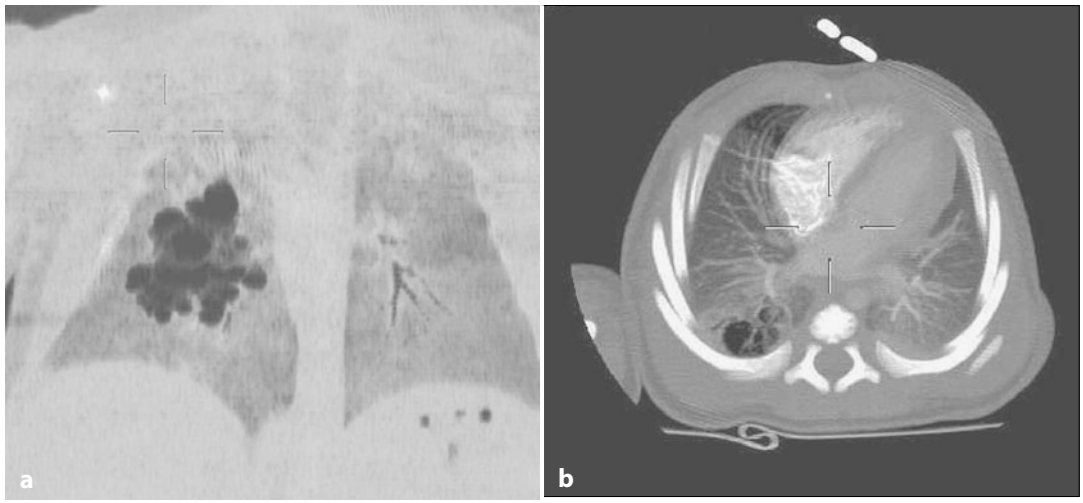

Fig. 3.14 MPR images: MinIP coronal (**a**) and axial MIP (**b**) showing right pulmonary CAM

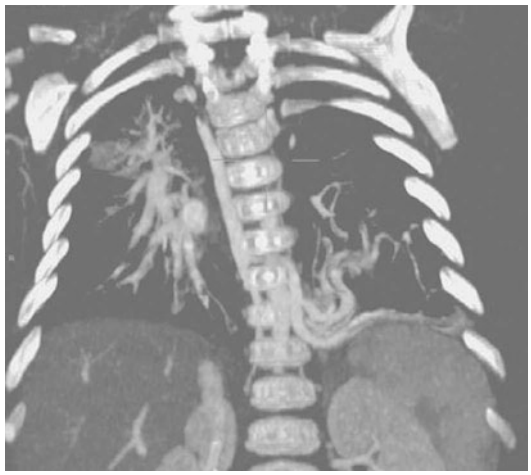

Fig. 3.15 MIP coronal MPR showing postero-basal left pulmonary sequestration

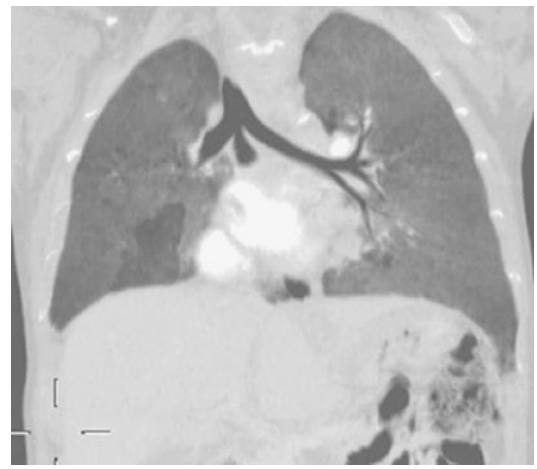

Fig. 3.16 MinIP coronal MPR showing right basal pulmonary sequestration

rather more obvious effects: they compress the esophagus, trachea and vascular structures of the airway.

CAM (Fig. 3.14) can be associated with macroscopic cysts. The anatomy and characteristics of these formations lend themselves to CT, which allows evaluation of communication of the cyst with the airways, and its blood supply from the pulmonary circulation. These malformations are often perfused by systemic vessels and distinguishing them from pulmonary sequestration is difficult. These malformations can be differentiated according to the size of the cysts (which may vary from a few millimeters to >10 cm). These malformations may be associated with other congenital abnormalities of the lung.

Pulmonary sequestration (Figs 3.15 and 3.16) comprises a mass of lung tissue that is not in communication with the airway, and which is perfused by a systemic-type vascular component. CT allows distinction between the

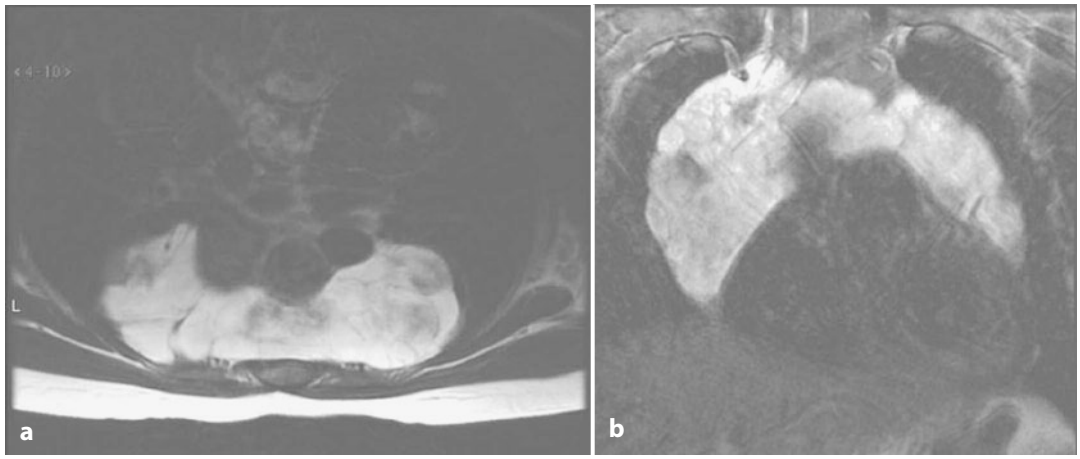

Fig. 3.17 Axial (**a**) and coronal T2-weighted (**b**) images showing a cystic neoplasm of the thymus gland

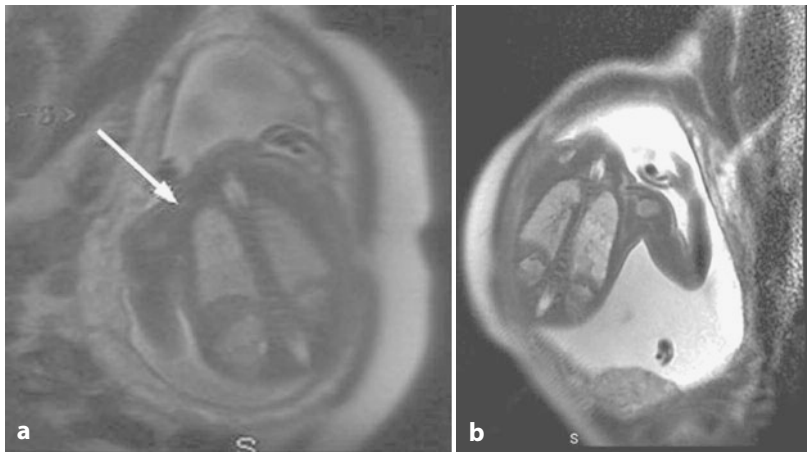

Fig. 3.18 Prenatal MRI (**a** and **b**) showing an adenomatoid cystic malformation

two types: intralobar (tissue is surrounded by normal lung tissue and located in the inner face of the visceral pleura) and extralobar (tissue is disconnected from the airways and has its own pleural lining). Venous drainage of the intralobar type is directed towards the pulmonary circulation, whereas extralobar sequestration is mediated by the system from the azygos portal.

3.5 MRI

For many years, MRI was considered to be an experimental method in the study of lung parenchyma. This judgment was based on the low-quality images it provided due to the many motion artifacts from breathing and heart beating as well as from the low signal/noise ratio. However, over the years, evolution of certain sequences (e.g., turbo spin echo (TSE) T2-weighted) and the use of triggers have extended the indications for the use of MRI in the lung. In the future, MRI may replace CT in follow-up examinations and the diagnosis of certain congenital lung malformations (e.g., pulmonary sequestration).

One of the main research areas in the study of the thorax in children is of mediastinal

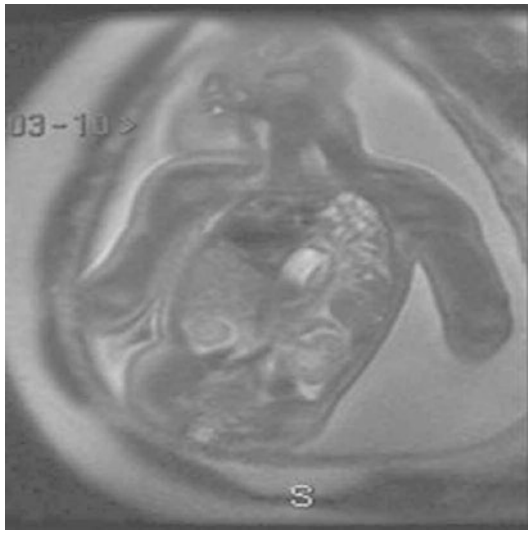

Fig. 3.19 Prenatal MRI showing a diaphragmatic hernia

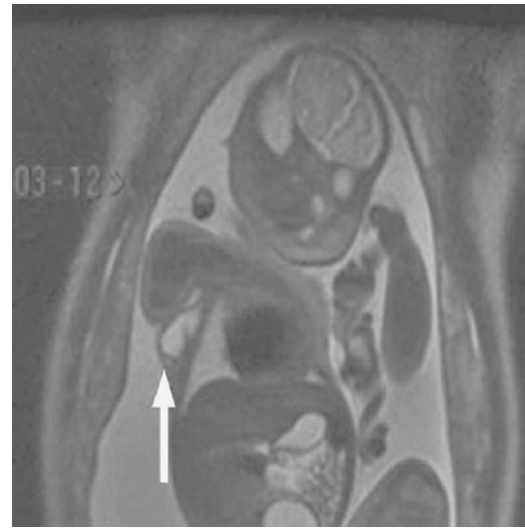

Fig. 3.20 Prenatal MRI showing a cystic lymphangioma

masses (particularly those of the posterior mediastinum). Imaging is with T1 and T2 TSE (Fig. 3.17) sequences and, in younger children (especially sedated subjects), single-shot sequences. MRI is also of utmost importance in prenatal diagnosis (Figs 3.18–3.20), particularly the study of congenital lung malformations (which are typically detected with US but which are then framed and evaluated with MRI).

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