

Contents

Preface					x
Contributors					xi
Abbreviations					xii
Part I Fundamentals of Diagnostic Thoracic Imaging					
1 Examination Technique					3
1.1 Projection Radiography	3	1.4.1 Introduction			10
1.1.1 Standing Position	3	1.4.2 Equipment Technology			12
1.1.2 Supine Radiographs	3	1.4.3 Pulse Sequences for Diagnostic Imaging			12
1.2 Fluoroscopy	5	1.4.4 Recommendations for Examination Protocols			14
1.3 Computed Tomography	6	1.5 Ultrasonography			16
1.3.1 High-Resolution Computed Tomography	6	1.6 Positron Emission Tomography–Computed Tomography			16
1.3.2 Low-Dose Computed Tomography	7	1.7 Image Reformatting			17
1.3.3 Special CT Examination Techniques	8	1.8 Computer-Assisted Diagnosis			17
1.3.4 Dual-Energy Computed Tomography	10	1.8.1 Computer-Assisted Detection			17
1.4 Magnetic Resonance Imaging	10	1.8.2 Volumetry			18
<i>Jürgen Biederer</i>					
2 Basic Anatomy					21
2.1 The Mediastinum	21	2.3.1 Hilar Structures			26
2.1.1 The Vascular System	21	2.3.2 The Lobes and Segments of the Lung			26
2.1.2 The Lymphatic System	24	2.3.3 Connective Tissue Compartments			27
2.1.3 The Trachea and Bronchi	24	2.3.4 The Lobule			27
2.1.4 The Thymus	25	2.4 The Pleura			28
2.2 The Heart and Pericardium	25	2.5 The Diaphragm			28
2.3 The Lung	26				
3 General Symptomatology					31
3.1 Projection Radiography	31	3.2.2 Nodular Opacities			35
3.1.1 Generic Signs	31	3.2.3 Increased Lung Opacity			37
3.1.2 Unilateral Changes in Radiolucency	31	3.2.4 Decreased Lung Opacity			37
3.1.3 Atelectasis	31	3.2.5 Cysts			37
3.2 Computed Tomography	33	3.2.6 Radiologic Signs of Fibrosis			37
3.2.1 Linear and Reticular Opacities	33				
4 Indications					40
Part II Diseases of the Chest and Special Findings					
5 Pneumonia					45
5.1 Community-Acquired Pneumonia	48	5.4 Mycobacteriosis			55
5.2 Hospital-Acquired/Nosocomial Pneumonia ..	49	5.4.1 Tuberculosis			55
5.3 Opportunistic Pneumonia	50	5.4.2 Atypical Mycobacteriosis			63
5.3.1 Fungal Pneumonia	51	5.5 Summary			64
5.3.2 Viral Pneumonia	54				

6	Diffuse Parenchymal Lung Diseases	68
6.1	Idiopathic Interstitial Pneumonias	68
6.1.1	The Role of Radiology	69
6.1.2	Idiopathic Pulmonary Fibrosis	69
6.1.3	Idiopathic Nonspecific Interstitial Pneumonia	71
6.1.4	Cryptogenic Organizing Pneumonia	72
6.1.5	Acute Interstitial Pneumonia	74
6.1.6	Respiratory Bronchiolitis-Interstitial Lung Disease	75
6.1.7	Desquamative Interstitial Pneumonia	76
6.1.8	Rare Idiopathic Interstitial Pneumonias	76
6.1.9	Familial Idiopathic Interstitial Pneumonia	77
6.1.10	Unclassifiable Idiopathic Interstitial Pneumonias	78
6.2	Diffuse Parenchymal Lung Diseases of Known Origin	78
6.2.1	Lung involvement in Systemic Autoimmune Diseases	78
6.2.2	Drug-Induced Lung Disease	82
6.2.3	Parenchymal Lung Diseases Due to Extrinsic Noxae	82
6.3	Granulomatous Parenchymal Lung Diseases	83
6.3.1	Sarcoidosis	83
6.3.2	Other Granulomatous Parenchymal Lung Diseases	87
6.4	Other Types of Diffuse Parenchymal Lung Diseases	87
6.4.1	Pulmonary Langerhans Cell Histiocytosis	88
6.4.2	Lymphangioleiomyomatosis	88
6.4.3	Pulmonary Alveolar Proteinosis	89
6.4.4	Vasculitis and Other Autoimmune Diseases of the Lung	90
6.5	Summary	92
6.5.1	Idiopathic Interstitial Pneumonia	92
6.5.2	Diffuse Parenchymal Lung Diseases of Known Origin	93
6.5.3	Granulomatous Parenchymal Lung Diseases	93
6.5.4	Other Diffuse Parenchymal Lung Diseases	94
7	Immunologic Diseases of the Lung	100
7.1	Allergic Pulmonary Diseases	100
7.1.1	Asthma	100
7.1.2	Allergic Bronchopulmonary Aspergillosis	100
7.1.3	Hypersensitivity Pneumonitis	102
7.2	Eosinophilic Lung Diseases	103
7.2.1	Simple Pulmonary Eosinophilia (Loeffler Syndrome)	104
7.2.2	Acute Eosinophilic Pneumonia	105
7.2.3	Chronic Eosinophilic Pneumonia	106
7.2.4	Bronchocentric Granulomatosis	106
7.2.5	Idiopathic Hypereosinophilic Syndrome	107
7.3	Summary	107
8	Chronic Obstructive Pulmonary Disease	110
8.1	Pulmonary Emphysema	110
8.1.1	Emphysema on Computed Tomography	110
8.1.2	Emphysema on Chest Radiography	114
8.2	Chronic Bronchitis	115
8.3	Bronchiectasis	116
8.4	Summary	118
9	Tumors of the Lung	121
9.1	Hamartoma	121
9.2	Atypical Adenomatous Hyperplasia	121
9.3	Lung Cancer	122
9.3.1	Classification	122
9.3.2	Imaging Findings	126
9.3.3	Staging	128
9.3.4	Treatment Concepts	133
9.3.5	Early Detection and Lung Cancer Screening	133
9.4	Carcinoid	133
9.5	Rare Malignant Tumors of the Lung	134
9.6	Pulmonary Lymphoma	135
9.7	Lung Metastases	136
9.7.1	Nodular Metastasis	136
9.7.2	Lymphangitic Carcinomatosis	138
9.8	Inflammatory Pseudotumor	139
9.9	Summary	139
10	Airway Diseases	144
10.1	Diseases of the Trachea and Mainstem Bronchi	144
10.1.1	Tracheal Stenosis and Stenosis of the Mainstem Bronchi	144
10.1.2	Tracheal Diverticula	144
10.1.3	Tracheal Rupture	144
10.1.4	Foreign Body Aspiration	145
10.1.5	Benign Tumors	146
10.1.6	Malignant Tumors	146
10.1.7	Inflammatory and Other Systemic Diseases	146

10.1.8	Saber Sheath Trachea	147	10.2.2	Bronchiolitis Obliterans and Constrictive Bronchiolitis	151
10.1.9	Tracheomalacia and Bronchomalacia	148	10.2.3	Other Forms of Bronchiolitis	151
10.2	Small Airway Diseases	148	10.3	Summary	152
10.2.1	Infectious Bronchiolitis	150			
11	Pleural Diseases	155			
11.1	Pneumothorax	155	11.4.2	Pleural Thickening	161
11.1.1	Imaging Findings	155	11.5	Pleural Tumors	161
11.1.2	Differential Diagnosis	157	11.5.1	Lipoma	161
11.2	Pleural Effusion	158	11.5.2	Pleural Mesothelioma	162
11.3	Pleural Empyema	159	11.5.3	Solitary Fibrous Pleural Tumor	165
11.4	Pleural Fibrosis	160	11.5.4	Pleural Carcinosis	165
11.4.1	Pleural Plaques	160	11.6	Summary	166
12	Mediastinal Diseases	169			
12.1	Mediastinal Lymphadenopathy	169	12.5.1	Mediastinal Masses of Low Density	171
12.2	Mediastinitis	169	12.5.2	Solid Mediastinal Tumors of the Anterior Mediastinum	174
12.3	Pneumomediastinum	170	12.6	Summary	177
12.4	Esophageal Tumors	171			
12.5	Mediastinal Tumors and Tumor-Like Masses	171			
13	Diseases of the Chest Wall and Diaphragm	180			
13.1	Infection	180	13.4	Diaphragmatic Paresis	183
13.2	SAPHO Syndrome	180	13.5	Diaphragmatic Hernia	185
13.3	Tumors of the Chest Wall	181	13.6	Deformities of the Chest Wall	185
13.3.1	Benign Tumors	181	13.7	Summary	186
13.3.2	Malignant Tumors	182			
14	Vascular Diseases	191			
14.1	Diseases of the Pulmonary Arteries	191	14.2	Diseases of the Pulmonary Veins	198
14.1.1	Acute Pulmonary Embolism	191	14.3	Diseases of the Aorta and Major Arteries	199
14.1.2	Chronic Thromboembolic Disease and Chronic Thromboembolic Pulmonary Hypertension	194	14.3.1	Acute Aortic Syndrome	199
14.1.3	Pulmonary Hypertension	196	14.3.2	Vasculitis of the Great Vessels	201
14.1.4	Swyer-James Syndrome	196	14.4	Summary	201
15	Chest Trauma	206			
15.1	Blunt Chest Trauma	206	15.1.4	Trunk Wall	208
15.1.1	Lung Parenchyma	206	15.1.5	Diaphragm	209
15.1.2	Mediastinum	206	15.2	Penetrating Chest Trauma	209
15.1.3	Pleural Space	208	15.3	Summary	210
16	Diagnostic Imaging of the Chest in Intensive Care Medicine	213			
16.1	Indications for Chest Radiography in Intensive Care Medicine	213	16.2.3	Pulmonary Artery Catheters (Swan-Ganz Catheter)	214
16.2	Detection and Malposition of Implanted Devices	213	16.2.4	Nasogastric Tubes	215
16.2.1	Tracheal Tubes	213	16.2.5	Chest Tubes	215
16.2.2	Central Venous Catheters	214	16.2.6	Intra-Aortic Balloon Pump	215
			16.2.7	Other Implanted Devices	216

16.3 Typical Findings in Intensive Care Unit Patients	216	16.5 Pulmonary Edema	218
16.4 Congestive Heart Failure	217	16.5.1 Hydrostatic Edema	218
16.4.1 Left-sided Congestive Heart Failure	217	16.5.2 Permeability Edema	219
16.4.2 Right-sided Congestive Heart Failure	218	16.6 Adult Respiratory Distress Syndrome	219
		16.7 Summary	220
17 Treatment-Related Changes	223		
17.1 The Postoperative Thorax	223	17.2 Bronchoscopic and Surgical Procedures for Treatment of Pulmonary Emphysema	237
17.1.1 Partial Lung Resection	223	17.2.1 Bronchoscopic Procedures	237
17.1.2 Pneumonectomy	226	17.2.2 Lung Volume Reduction Surgery	238
17.1.3 Surgery for Pleural Diseases	227	17.3 Radiotherapy	238
17.1.4 Surgery for Pneumothorax	229	17.4 Chemotherapy	238
17.1.5 Lung Transplantation	229	17.5 Stem Cell Transplantation	238
17.1.6 Heart Surgery	232	17.5.1 Complications of Stem Cell Transplantation	238
17.1.7 Esophageal Surgery	234	17.5.2 Graft-versus-Host Disease	239
17.1.8 General Complications of Thoracic Surgery	235	17.6 Summary	239
18 Occupational Lung Diseases	243		
<i>Beate Rehbock</i>			
18.1 Introduction	243	18.3.5 Malignant Occupational Diseases of the Lung and Pleura	247
18.2 Imaging Modalities	243	18.4 Diagnostic Imaging of Special Disease Entities	247
18.2.1 Chest Radiography	243	18.4.1 Asbestosis and Asbestos Dust-Related Pleural Disease	247
18.2.2 Computed Tomography	243	18.4.2 Silicosis	250
18.2.3 Other Imaging Modalities	243	18.4.3 Hypersensitivity Pneumonitis	253
18.3 Disease Entities	243	18.4.4 Occupational Malignant Thoracic Tumors	254
18.3.1 Inorganic Dust-Induced Lung Diseases (Pneumoconiosis)	243	18.5 Summary	256
18.3.2 Organic Dust-Induced Lung Diseases	246		
18.3.3 Acute Inhalation Toxicity	247		
18.3.4 Chronic Bronchitis and Asthma	247		
19 Congenital Thoracic Diseases and Malformations	259		
19.1 Congenital Lobar Emphysema	259	19.5.2 Anomalous Pulmonary Venous Drainage	262
19.2 Bronchial Atresia	259	19.6 Pulmonary Arteriovenous Malformation	262
19.3 Congenital Pulmonary Airway Malformation	259	19.7 Underdevelopment of the Lung	263
19.4 Bronchogenic Cysts	260	19.8 Bronchopulmonary Sequestration	263
19.5 Vascular Anomalies	261	19.9 Scimitar Syndrome	264
19.5.1 Anomalies of the Pulmonary Arteries	261	19.10 Summary	264
20 Nonvascular Interventions	267		
20.1 Biopsy	267	20.2.3 Technique	269
20.1.1 Indications	267	20.2.4 Complications	269
20.1.2 Preprocedure Assessment	267	20.3 Thermal Ablation of Lung Tumor	269
20.1.3 Technique	268	20.3.1 Indications	269
20.1.4 Complications	268	20.3.2 Technique	270
20.2 Drainage Therapy	268	20.3.3 Complications	271
20.2.1 Indications	268		
20.2.2 Preprocedure Assessment	268		

Part III Differential Diagnostic Considerations and Incidental Findings

21 Pulmonary Nodules	275		
21.1 Solitary Nodule	275	21.2 Multiple Nodules	279
21.1.1 Differential Diagnosis	275	21.2.1 Differential Diagnosis	280
21.1.2 Management	276	21.2.2 Management	283
22 Cavities	287		
23 Persistent or Migratory Pulmonary Infiltrates	289		
23.1 Raised Inflammatory Markers	289	23.2 Normal Inflammatory Markers	292
23.1.1 Infection	289	23.2.1 Lung Cancer	292
23.1.2 Cryptogenic Organizing Pneumonia	290	23.2.2 Diffuse Alveolar Hemorrhage	292
23.1.3 Eosinophilic Pneumonia	290	23.2.3 Allergic Bronchopulmonary Aspergillosis	292
23.1.4 Vasculitis	291	23.2.4 Pulmonary Alveolar Proteinosis	292
23.1.5 Radiation Pneumonitis	292		
24 Diagnostic Schema for Typical Computed Tomography Findings of Diffuse Pulmonary Diseases ..	295		
24.1 Main Finding: Interlobular Septal Thickening	297	24.4 Main Finding: Ground-Glass Opacities	301
24.2 Main Finding: Intralobular Lines	298	24.5 Main Finding: Consolidations	303
24.3 Main Finding: Nodules	299	24.6 Main Finding: Cysts	304
Part IV Glossary			
25 Fleischner Society Glossary of Terms for Thoracic Imaging	307		
25.1 Preliminary Remarks	307	25.3 Additional Definitions	338
25.2 Glossary	307		
Index	343		

Part I
**Fundamentals of
Diagnostic Thoracic
Imaging**

1 Examination Technique	3
2 Basic Anatomy	21
3 General Symptomatology	31
4 Indications	41



Chapter 1

Examination Technique

1.1 Projection Radiography	3
1.2 Fluoroscopy	5
1.3 Computed Tomography	6
1.4 Magnetic Resonance Imaging	10
1.5 Ultrasonography	16
1.6 Positron Emission Tomography- Computed Tomography	16
1.7 Image Reformatting	17
1.8 Computer-Assisted Diagnosis	17



1 Examination Technique

This chapter describes specific aspects of examining the chest organs with the different imaging modalities. It is outside the scope of this textbook to give a comprehensive overview of the technical aspects of the equipment or the positioning techniques. These details can be consulted in the pertinent literature.^{1,2}

1.1 Projection Radiography

The following descriptions relate to digital radiography (flat panel detector or image plate). By now this is available in most radiology institutions. This chapter does not take account of older, conventional screen-film radiography systems but many aspects are very similar to that of digital radiography.

For almost all chest diseases, chest radiography constitutes the first step in diagnostic imaging. The few exceptions to that rule (e.g., suspected pulmonary embolism) will be pointed out in the relevant sections.

1.1.1 Standing Position

Patients are X-rayed in a standing position, whenever their condition permits. The standing patient is X-rayed in the PA (posteroanterior) beam path with the chest placed against the detector (*PA image*), while the focus detector distance is 1.4 to 2 m. ▶ Table 1.1 summarizes the technical radiographic parameters. To avoid overlapping of the pulmonary fields, the scapulae must be rotated laterally. To that effect, the patient places his/her hands on the hips while rotating the elbows anteriorly as far as possible. Alternatively, the patient clasps the detector with their arms; this, too, assures anterior rotation of the scapulae.

If because of the patient's general condition an X-ray cannot be taken in a standing position, this can be done with the patient sitting down. The patient leans his/her back against the detector; the beam path is therefore oriented in an AP direction (anteroposterior; *AP image*). As a result, the diaphragm will be positioned at a higher level than seen in a standing radiograph, the inspiration depth is reduced, and, accordingly, the basal lung segments are less well ventilated.

Likewise, a *lateral radiograph* is obtained with the patient standing and the arms raised. Normally, the patient's left side

rests against the detector. In general, a clearer image will be obtained of the lung closer to the detector compared with that farther away from the detector. If the clinical diagnostic indication calls for maximum image quality and the critical details are difficult to identify, in certain cases to visualize a right-sided pathology it may be advisable to take an image with the right side placed against the detector.

All radiographs of the chest organs should be obtained in deep inspiration. The *expiratory image* usually used in the past to exclude pneumothorax is now obsolete for several reasons^{3,4}:

- The expiratory radiograph does not permit assessment of the cardiopulmonary status since the lung is inadequately ventilated and the pulmonary vessels appear dilated. This can obscure other relevant findings, e.g., small pulmonary infiltrates or incipient congestive heart failure.
- Comparability with previous or subsequent radiographs is not possible.
- With modern digital equipment technology, a pneumothorax of clinically relevant size can also be recognized on an inspiratory radiograph.

The European Guidelines on Quality Criteria for Diagnostic Radiographic Images issued by the European Commission define criteria to be met by radiographs.⁵ ▶ Table 1.2 lists the criteria specified for the image quality of overview chest radiographs.

Note

For radiographic diagnosis of chest organs, a *high-energy X-ray* taken with a high tube voltage is used. Calcified structures will appear radiolucent on such radiographs. This reduces the otherwise disruptive overlying of the pulmonary fields by the ribs (▶ Fig. 1.1). Besides, osseous structures allow only limited assessment. Therefore, for diagnostic issues related to the thoracic skeleton, e.g., exclusion of rib fractures, a *low-energy X-ray* is needed with 60 to 75 kV tube voltage.

1.1.2 Supine Radiographs

For diagnostic imaging of bedridden patients, in particular in intensive care settings, supine radiographs are normally

Table 1.1 Radiographic parameters for PA and lateral radiographs⁵

Imaging parameters	PA projection	Lateral projection
Scanner type	Vertical stand with stationary or moving grid	Vertical stand with stationary or moving grid
Tube voltage	125 kV	125 kV
Focal spot value	≤1.3	≤1.3
Total filtration	≥3.0 mm Al equivalent	≥3.0 mm Al equivalent
Focus detector distance	180 cm (140–200 cm)	180 cm (140–200 cm)
Automatic exposure control	Right lateral chamber selected	Central chamber selected
Exposure time	<20 ms	<20 ms
Antiscatter grid	$r = 10; 40/\text{cm}$	$r = 10; 40/\text{cm}$
Nominal speed class	SC 400	SC 400
Entrance surface dose for standard-sized patient	0.3 mGy	1.5 mGy

Table 1.2 Quality requirements for chest radiographs⁵

Requirements	PA/AP thorax	Lateral thorax
Image criteria	<ul style="list-style-type: none"> Performed at full inspiration (as assessed by the position of the ribs above the diaphragm—either 6 anteriorly or 10 posteriorly) and with suspended respiration Symmetrical reproduction of the thorax as shown by central position of the spinous process between the medial ends of the clavicles Medial border of the scapulae should be projected outside the lung fields Reproduction of the whole rib cage above the diaphragm Visually sharp reproduction of the vascular pattern in the whole lung, particularly the peripheral vessels Visually sharp reproduction of: <ul style="list-style-type: none"> The trachea and proximal bronchi The borders of the heart and aorta The diaphragm and lateral costophrenic angles Visualization of the retrocardiac lung and the mediastinum 	<ul style="list-style-type: none"> Performed at full inspiration and with suspended respiration Arms should be raised clear of the thorax Superimposition of the posterior lung borders Reproduction of the trachea Reproduction of the costophrenic angles Visually sharp reproduction of the posterior border of the heart, the aorta, mediastinum, diaphragm, sternum, and thoracic spine
Important image details	<ul style="list-style-type: none"> Small round details in the whole lung, including the retrocardiac areas: <ul style="list-style-type: none"> High contrast: 0.7 mm diameter Low contrast: 2 mm diameter Linear and reticular details out to the lung periphery: <ul style="list-style-type: none"> High contrast: 0.3 mm in width Low contrast: 2 mm in width 	<ul style="list-style-type: none"> Small round details in the whole lung: <ul style="list-style-type: none"> High contrast: 0.7 mm diameter Low contrast: 2 mm diameter Linear and reticular details out to the lung periphery: <ul style="list-style-type: none"> High contrast: 0.3 mm in width Low contrast: 2 mm in width

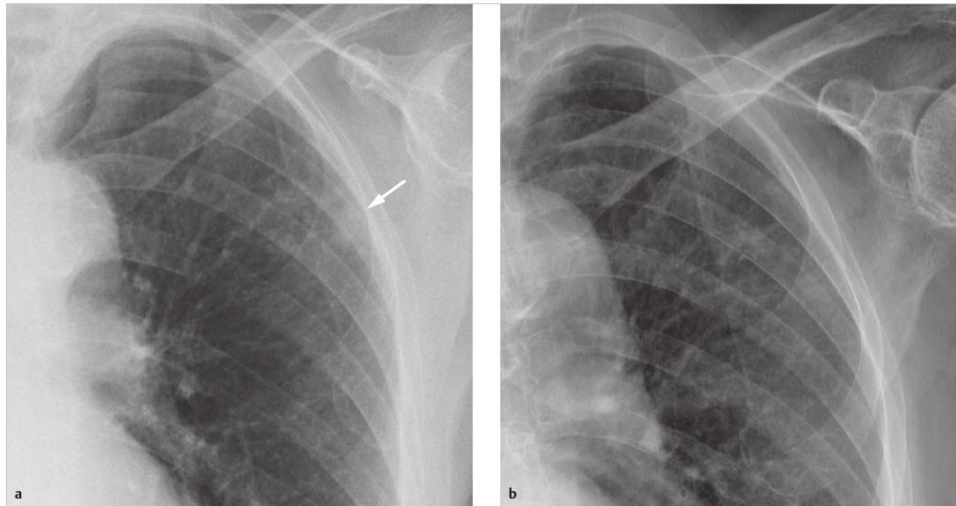


Fig. 1.1 High-energy and low-energy chest radiographs. Different detectability of bone structures. Bronchopneumonia in the left upper lobe is much easier to detect on the high-energy radiograph (a, arrow). (a) High-energy radiograph with 125 kV tube voltage. (b) Low-energy radiograph with 70 kV tube voltage.

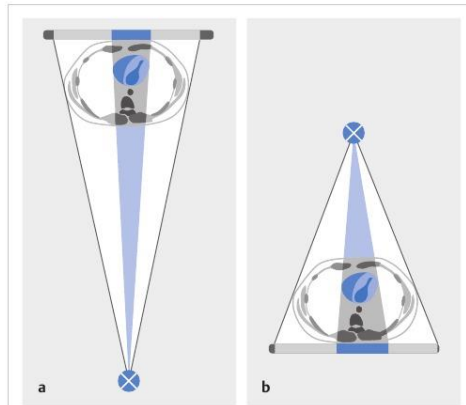


Fig. 1.2 Geometric distortion in standing and supine radiographs. Schematic diagram. **(a)** Standing PA radiograph with large focus detector distance: low magnification of cardiac opacity. **(b)** Supine AP radiograph with small focus detector distance: high magnification of cardiac opacity.



Fig. 1.4 Grid artifact. Radiograph (supine radiograph). Different radiolucency of both axillae (arrows) as distinguishing feature of that artifact.

obtained. The mobile detector is positioned beneath the thorax of the supine patient and the tube of the mobile radiography unit is placed above the patient. The focus detector distance should be 90 to 120 cm. For several reasons, supine radiographs have poorer image quality than standing or sitting radiographs:

- The reduced focus detector distance results in greater geometric distortion; the mediastinal width and heart size appear enlarged on the supine radiograph (► Fig. 1.2); the

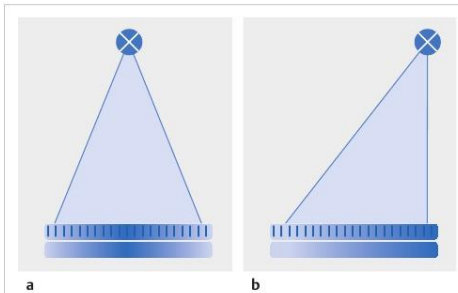


Fig. 1.3 Grid artifact because of decentered X-ray tube. Schematic diagram. **(a)** Normal image: symmetric radiolucency of both hemithoraces. **(b)** Grid artifact: the decentered tube causes right hemithorax opacity.

heart is farther away from the detector, showing greater geometric enlargement.

- The diaphragm is higher, resulting in reduced inspiration depth.
- Lung perfusion has no gravity-mediated caudocranial gradient; it is not possible to diagnose pulmonary blood flow redistribution.
- Since the tube voltage used is lower, bone superimposition is more pronounced.
- The lower generator power of mobile radiography units results in a longer exposure time and is likely to cause motion blur due to breathing or heart pulsations.

Note

The imaging position (standing, sitting, supine) should be noted on the radiograph. Besides, for mechanically ventilated patients, information on the ventilation parameters is helpful for image interpretation, in particular on the positive end expiratory pressure (PEEP).

The use of an antiscatter grid can enhance the image quality for obese patients, albeit at the expense of higher radiation exposure. A characteristic artifact is observed if the X-ray tube is not positioned above the middle of the detector fitted with an antiscatter grid (► Fig. 1.3). To distinguish this artifact from pathologic hemithorax opacity, it may be useful to compare radiolucency of both axillae (► Fig. 1.4). Unequal radiolucency is suggestive of a *grid artifact*.

Skin folds on the patient's back result from placement of the X-ray detector between the bed and patient and can mimic pneumothorax (pseudo-pneumothorax).

1.2 Fluoroscopy

Chest fluoroscopy is mainly used for functional assessment of diaphragmatic movement. A standardized fluoroscopy examination procedure is described.⁶

Before commencing fluoroscopy examination, the patient practices deep breathing with the mouth open. In addition, the patient should repeat the sniff test around twice: the patient breathes deeply in and out with the mouth open, closes the mouth, and, again, with the mouth closed, breathes in deeply and strongly as fast as possible. The patient repeats this procedure once.

During examination, the patient stands against the vertically tilted fluoroscope. If the patient cannot be examined in a standing position because of their general condition, the patient sits on the footplate of the fluoroscope. The image section is centered vertically on the diaphragm and the image is collimated laterally as far as necessary. Next the patient breathes normally two to three times under fluoroscopic guidance, and then takes two to three forced breaths in and out. This is followed by conduct of the sniff test, also two to three times. The patient is then rotated by 90° and the examination sequence described is repeated in the lateral beam path.

The image documentation comprises the fluoroscopy video sequences of the PA and lateral fluoroscopy images which are digitally archived.

1.3 Computed Tomography

The enormous innovative boost experienced over the past two decades in computed tomography (CT) technology has greatly enhanced scanner performance. This, too, has led to increasing diversification of the technical features of CT equipment. Currently, scanners with a row count of between 1 and 640 are used for routine imaging. As such, standardization of examination protocols is virtually impossible. Various valuable internet sources of information provide vendor-specific CT examination protocols (e.g., www.ctisus.com). Below are listed some basic aspects to be considered in *CT examination protocols*:

- **Radiation exposure:** Tube voltage, tube current, and pitch should be adjusted such that the radiation exposure complies with the reference values specified for diagnostic imaging of patients of normal weight. Relevant reference values vary greatly among different countries.⁷
- **Tube voltage:** For most applications, a tube voltage of 110 to 120 kVp is suitable. For computed tomography angiography (CTA), the tube voltage may be reduced in certain circumstances to 80 to 100 kVp, in particular for pediatric or slim patients.^{8,9}
- **Automatic tube current modulation:** Due to the major differences in the absorption profiles of the thorax in the craniocaudal and axial directions, the use of automatic tube current modulation has greatly contributed to dose reduction.⁸ However, there is a risk of this automated facility preselecting a very high tube current for obese patients. It is therefore recommended to limit the maximum tube current in the scan parameters if this is technically possible. Other considerations apply for low-dose CT.
- **Slice thickness:** The detector configuration should provide for a reconstructed slice thickness of 1 to 1.5 mm. But that does not apply to CT scanners with a limited row count, for which a compromise has to be made between the minimum slice

thickness possible and the scan duration. A limiting factor for the slice thickness in such cases is the maximum length of breath suspension that can be maintained before breathing artifacts degrade the image quality. There does not appear to be much benefit in selecting a slice thickness of substantially less than 1 mm in the thoracic region because of the ensuing rise in image noise; a reduced slice thickness is unlikely to confer any additional diagnostic insights of relevance.

- **Image reconstructions recommended for routine examinations:**
 - 5 mm axial for quick orientation also for the referring physician (soft-tissue and lung kernel).
 - Axial thin-slice reconstructions (1.5–3 mm) with soft-tissue kernel, in CTA possibly reduced slice thickness.
 - Axial thin-slice reconstructions (1–1.5 mm) with lung kernel to allow for volumetric measurements.
 - 3–5 mm coronal and sagittal.
- **Overlapping of thin-slice reconstructions:** To achieve a good image quality for 3D (three-dimensional) reformatting of image data and precise volumetry, overlapping reconstruction of the thin-slice series by at least 20% of slice thickness is recommended.
- **IV contrast:** If IV contrast administration is indicated, a fixed delay of 40 s may be used for most diagnostic purposes. Alternatively, a bolus tracking procedure could be employed. Here the arrival of the contrast bolus in the descending aorta triggers the scan. An additional delay of a few seconds is advisable, for example, to accentuate the contrast between a tumor and its surrounding tissues. The use of CTA for diagnostic exploration of pulmonary embolisms requires bolus tracking or a test bolus in the pulmonary trunk or right ventricle.
- **Scanning direction:** Examination is performed in deep inspiration. A caudocranial scanning direction helps to reduce breathing artifacts. First, the basal lung regions most susceptible to breathing artifacts are scanned, followed by the less susceptible apical regions. Furthermore, with appropriate contrast medium timing, beam hardening artifacts caused by highly concentrated contrast material in the superior vena cava and brachiocephalic veins can be reduced.

1.3.1 High-Resolution Computed Tomography

The term “high-resolution computed tomography” (HRCT) dates back to the early 1980s.¹⁰ While that term has proved immutable over the past some 30 years, the underlying examination technology has undergone rapid development. Back then the body region to be scanned could only be visualized in sequential single slices, and acquisition of slices of 10-mm thickness represented the normal standard. Since each individual slice was acquisitioned in a separate breath-hold phase, imaging the entire lung took a lot of time.

Due to its low spatial resolution in the z-direction, the thick-slice CT was of limited value for differential diagnosis of diffuse lung parenchymal diseases. This differential diagnosis requires the assignment of pathologic changes to the structures of the