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Review / Derleme

Radiological imaging and interventional procedures of the thorax in children

Çocuklarda toraksın radyolojik görüntülenmesi ve girişimsel işlemleri

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ABSTRACT

The thoracic region in pediatric patients poses unique diagnostic and interventional challenges, necessitating specialized approaches in radiological imaging and procedures. This review provides an overview of the key considerations, techniques, and clinical significance in the field of pediatric thoracic radiology and interventions. We discuss the importance of age-appropriate imaging modalities and the application of advanced technologies in assessing a wide range of thoracic conditions in children, including congenital anomalies, infections, neoplasms, and trauma. Furthermore, we highlight the evolving role of minimally invasive interventional procedures in the management of pediatric thoracic disorders. As the understanding of pediatric thoracic pathology continues to expand, this review aims to guide healthcare professionals, radiologists, and pediatricians in delivering optimal care to children with thoracic concerns.

Keywords: Lung ultrasound, pediatric radiography, thorax computed tomography.

ÖZ

Pediatrik hastalarda torasik bölge, radyolojik görüntüleme ve işlemlerde özel yaklaşımlar gerektiren benzersiz tanısal ve girişimsel zorluklar ortaya çıkarmaktadır. Bu derleme pediatrik toraks radyolojisi ve müdahaleleri alanındaki temel hususlara, tekniklere ve klinik öneme ilişkin genel bir bakış sunmaktadır. Çocuklarda konjenital anomaliler, enfeksiyonlar, neoplazmlar ve travma dahil olmak üzere çok çeşitli torasik patolojilerin değerlendirilmesinde yaşa uygun görüntüleme yöntemlerinin ve ileri teknolojilerin uygulanmasının önemini tartışıyoruz. Ayrıca, pediatrik torasik hastalıkların tedavisinde minimal invazif girişimsel işlemlerin gelişen rolünü vurguluyoruz. Pediatrik torasik patolojiye ilişkin anlayış genişlemeye devam ettikçe, bu derleme sağlık uzmanlarına, radyologlara ve pediatri uzmanlarına göğüs sorunları olan çocuklara en uygun bakımı sunma konusunda rehberlik etmeyi amaçlamaktadır.

Anahtar sözcükler: Akciğer ultrasonu, pediatri radyografi, toraks bilgisayarlı tomografisi.

Evolving technology is increasing the contribution of radiological imaging methods to the diagnosis and treatment of diseases. Radiological imaging methods should be used with appropriate algorithms in the diagnosis, follow-up, and response evaluation in treating diseases affecting the thoracic region in childhood. The aim should be to ensure that the imaging performed is the least harmful and most suitable for the patient's complaint, preliminary diagnoses, and differential diagnosis; it should have a low cost and be easily accessible and easily repeatable if necessary. Therefore, it is of great importance to understand the general characteristics of radiological examinations and the collaboration between the clinician and the radiologist to achieve a diagnosis as soon and efficiently as possible.

The thoracic region in pediatric patients is evaluated using various imaging methods, including direct radiography, fluoroscopy, ultrasonography (USG) with color Doppler, computed tomography (CT) with high-resolution CT (HRCT), and spiral, multislice, and multidetector tomography, CT angiography, magnetic resonance imaging (MRI) with magnetic resonance angiography, and conventional angiography with digital subtraction angiography. These techniques offer a comprehensive assessment of the thoracic region, allowing healthcare professionals to obtain detailed images and examine the area thoroughly.

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CHEST X-RAY

The most frequently and dominantly preferred method of thorax imaging in both children and adults is direct radiography. However, chest radiography is one of the more difficult examinations to perform, particularly considering the diversity of tissue densities and thorax widths in the childhood age group and the inherently low-contrast tissues of children.[1] A standard chest radiograph is taken in the anteroposterior (AP) position in newborns and early childhood and in the posteroanterior (PA) position in older ages. Cardiac magnification is greater in AP radiographs and radiographs obtained with the patient lying down (portable radiographs in intensive care units); because the heart is farther from the film, it appears relatively larger. For a similar reason, the mediastinum appears wider in AP radiographs (Figure 1), and it is difficult to detect it in radiographs of patients lying down, as pleural fluid and air resulting in pneumothorax will spread. The anterosuperior mediastinum, retrocardiac area, and subdiaphragmatic lung areas, which cannot be evaluated well in AP or PA radiographs due to superposition, are evaluated with lateral radiography, which yields standard left side radiographs. The rationale for this approach is to reduce cardiac magnification. However, if local pathology is considered and the side is specified, the pathological side is positioned close to the cassette, thus providing edge sharpness in the lesion on that side.[2]

Depending on the clinical condition of the patient, some special projections can be used in addition to standard two-view radiography; the main ones are apicolordotic radiography, expiratory radiography, lateral decubitus radiography, oblique radiographs, and cross table lateral radiography.[1,3]

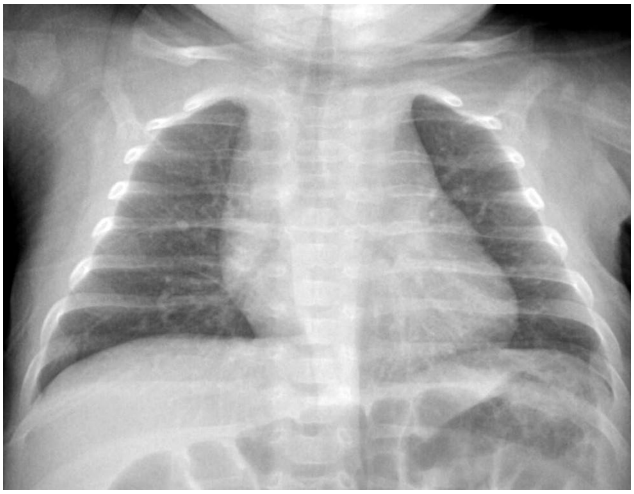

Figure 1. In an anteroposterior chest radiograph, increased expiratory opacity and mediastinal width are observed in both lung parenchyma. The thymus causes the mediastinal widening in the image, as it shortens and expands during expiration.

- Lung apices may not be evaluated optimally in standard radiographs, so an apicolordotic radiograph is taken when apical lesions are suspected to prevent the superposition of the apices and the clavicles. Right lung middle lobe collapse is also well visualized in this projection.
- Expiratory radiographs, used to show air trapping and pneumothorax, are particularly useful in children when foreign body aspiration is suspected. In the case of foreign body aspiration, expiratory radiographs are useful in confirming the diagnosis, as air trapping will continue on that side during expiration.
- A lateral decubitus radiograph is used to evaluate small amounts of pleural fluid, subpulmonary fluid, and pneumothorax. In the presence of effusion, the patient is laid on the suspected side, and the fluid should level out below. If 5 mL or more of fluid collects in the pleural space, it can be seen in a lateral decubitus radiograph. The equivalent amount is 75 mL to merit lateral radiography and 175 mL for PA radiography. In cases of pneumothorax, the patient is laid on the healthy side, the suspected side remains up, and the pleural air is collected above.[1] Today, the most sensitive examination for pleural fluid is USG.
- The main indications for oblique radiographs are the evaluation of sternum and rib fractures and the detection of tumor pathologies and pleural plaques in those areas. It is now accepted that CT is more advantageous for evaluating pathologies other than rib fractures.
- Cross table lateral radiography is an imaging method used in the diagnosis of pneumomediastinum and pneumoperitoneum in the neonatal period and in babies younger than six months. It is obtained by taking a lateral X-ray while the patient is in the supine position. Free air in the mediastinum or peritoneal cavity collects above.

When evaluating a chest radiograph, its technical suitability should first be determined. Radiographs that are technically inappropriate, improperly facing, without sufficient inspiration, with inadequate

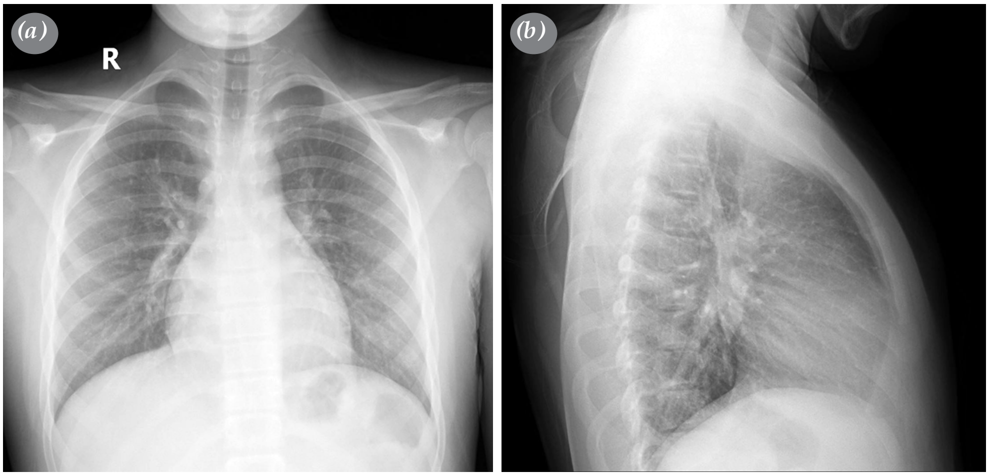

Figure 2. Properly positioned **(a)** posteroanterior and **(b)** lateral chest radiographs.

or excessive X-ray dose, or with improper beam centralization may lead to erroneous evaluations and unnecessary further examination or invasive procedures for the patient, as well as potentially concealing an existing pathology.

During patient positioning, both hemithoraxes should equally contact the cassette. Without equal contact, the side with more contact with the cassette will be more radiolucent. The most practical way to determine whether the radiograph is symmetrical is to look at the ribs and clavicles. In a properly positioned radiograph, the ribs and clavicles should be symmetrical. On the side of rotation, the ribs appear short in front, and they appear long in the back.

Another important concern in an optimal radiograph is adequate inspiration. It is difficult to achieve breathing cooperation in childhood, specifically in young children. In older age groups, the ribs are counted to determine whether the image constitutes an inspiration radiograph. In a good inspiration radiograph, the diaphragmatic border on the PA radiograph should be at the level of the fifth and sixth anterior ribs or the 10th and 11th posterior ribs (Figure 2). Unlike in adults, the rib cage expands in all directions in infants, the diaphragmatic contribution is very small, and it is difficult to distinguish between inspiration and expiration. In a radiograph taken during expiration, it is observed that the lungs are less ventilated; the

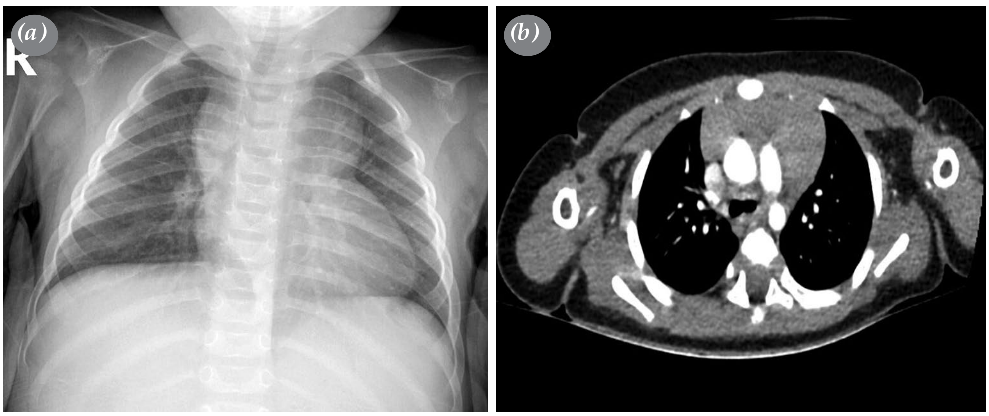

Figure 3. (a) In a one-year-old male patient admitted with cough, a wide mediastinum is observed on chest radiography. Note that the structure that causes the mediastinal expansion creates a wave sign on the ribs. In the plain radiograph, note that the tracheal deviation to the right is caused by the effect of expiration and that the tissue forming the mediastinal expansion does not cause a significant narrowing of the trachea. **(b)** The contrast-enhanced thorax computed tomography examination of the same patient shows that the tissue that creates the mediastinal expansion is the thymus tissue.

middle and lower zones appear more radiopaque, and the contour of the diaphragm is observed to be unclear.

Radiographs should be interpreted in a systematic order. Depending on personal preference, this may start from the inside to outside or reverse. For example, a clinician starting from the outside can sequentially evaluate the chest wall soft tissues and bone structures, the diaphragm, pleural area, sinuses, heart/mediastinum, hilus, vascular structures, and lung parenchyma.

In the evaluation of chest radiographs in children, it is crucial to know the normal anatomy, as well as variations and age-related changes. The main misleading tissue on radiographs in childhood is the thymus gland, which can cause mediastinal expansion and be mistaken for a mass (Figure 3). The thymus is quite visible on chest radiographs from birth to three years of age, being at its largest volume in relation to the body, particularly in the first two years. The presence of a thymus can sometimes be observed until late adolescence. In some cases, rebound hyperplasia may occur after atrophy caused by certain diseases that induce systemic stress or as a result of chemotherapy/steroid treatment. It is important to know that a normal thymus does not put pressure on adjacent anatomical-vascular structures. Thymic hyperplasia does not cause any pressure on the surrounding tissues. On radiographs, the thymus has four corners, and its edges are convex or straight.

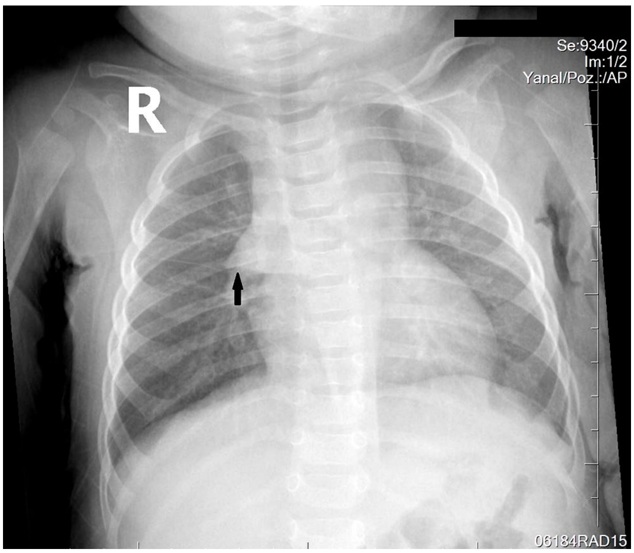

Figure 4. The typical cardiothymic notch appearance accompanying mediastinal expansion in a one-year-old patient, marked with a black arrow, supporting the conclusion that the expansion belongs to the thymus.

After the age of five, the edges of the thymus become concave. The thymus gland can be observed in various configurations. Three main findings suggest that the structure appearing on a radiograph belongs to the thymus. One is the cardiothymic notch, which is observed to extend into the minor fissure where the thymus meets the heart (Figure 4). The second is the sail sign, the more obvious form of the cardiothymic notch, which is the wave sign observed in the thymic tissue due to the compression of the ribs on the thymus. During inspiration, the thymus narrows and lengthens, while during expiration, it expands and shortens.[4]

If, despite these defined signs, it is impossible to distinguish whether the cause of mediastinal enlargement is a normal or hyperplasic thymus or another mass lesion, USG examination can distinguish the thymus. When examined from the suprasternal notch by USG, a typical appearance of the thymus is observed. In USG, the normal thymus tissue is observed as a hypoechoic parenchyma with a homogeneous internal structure and punctate echogenicity within that parenchyma, and its echo pattern is similar to that of the liver parenchyma (Figure 5). It does not cause any pressure on the adjacent aorta, its branches, or the superior vena cava and can be observed to fill the spaces between the vascular structures. Computed tomography or MRI can evaluate lymphoma located in the anterior mediastinum, infiltration due to leukemia, or focal lesions located in the thymus.

A cardiothoracic ratio of up to 60% is considered normal in the infantile period, but it gradually decreases with age to 50% in adults.[5] If an increase is observed in the cardiothoracic ratio, lung vascularity should be evaluated. Pulmonary vascular structures should not be observed in the peripheral third of the lung parenchyma. If peripheral pulmonary vascular

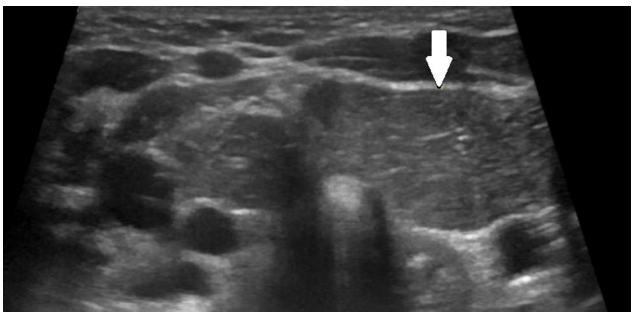

Figure 5. The white arrow shows the normal ultrasonographic appearance of the thymus. In addition to the typical echo pattern, it is important to recognize that the thymus does not create a compressive effect on the adjacent vascular structures and that it indents into the fatty tissue between the neighboring structures.

structures are observed on an optimally obtained radiograph, it can be concluded that pulmonary vascularity has increased. To evaluate the situs on standard radiographs, clinicians should examine the bronchial anatomy, position of gastric gas, shadow of the descending and ascending aorta, and the location of the aortic knob. If there is a right aortic arch, congenital heart diseases should be investigated.

The appearance of the hilus also changes with age. The hilus contour is unclear in the newborn period, and hilus opacity gradually increases with age. Another common misperception in childhood radiographs is the tracheal deviation observed in the infantile period, which is called tracheal buckling. During the infantile period, the trachea has a mobile structure and can be angled forward and laterally or displaced. A slight deviation of the trachea to the right is a normal appearance in the neonatal period, and this deviation becomes more evident during expiration (Figure 3a). The condition that causes the trachea to deviate to the right is the compression of the aortic arch from the left. This image should not be considered a mass pressing or pushing on the trachea.[6] If the trachea does not deviate to the right during the infantile period, the right aortic

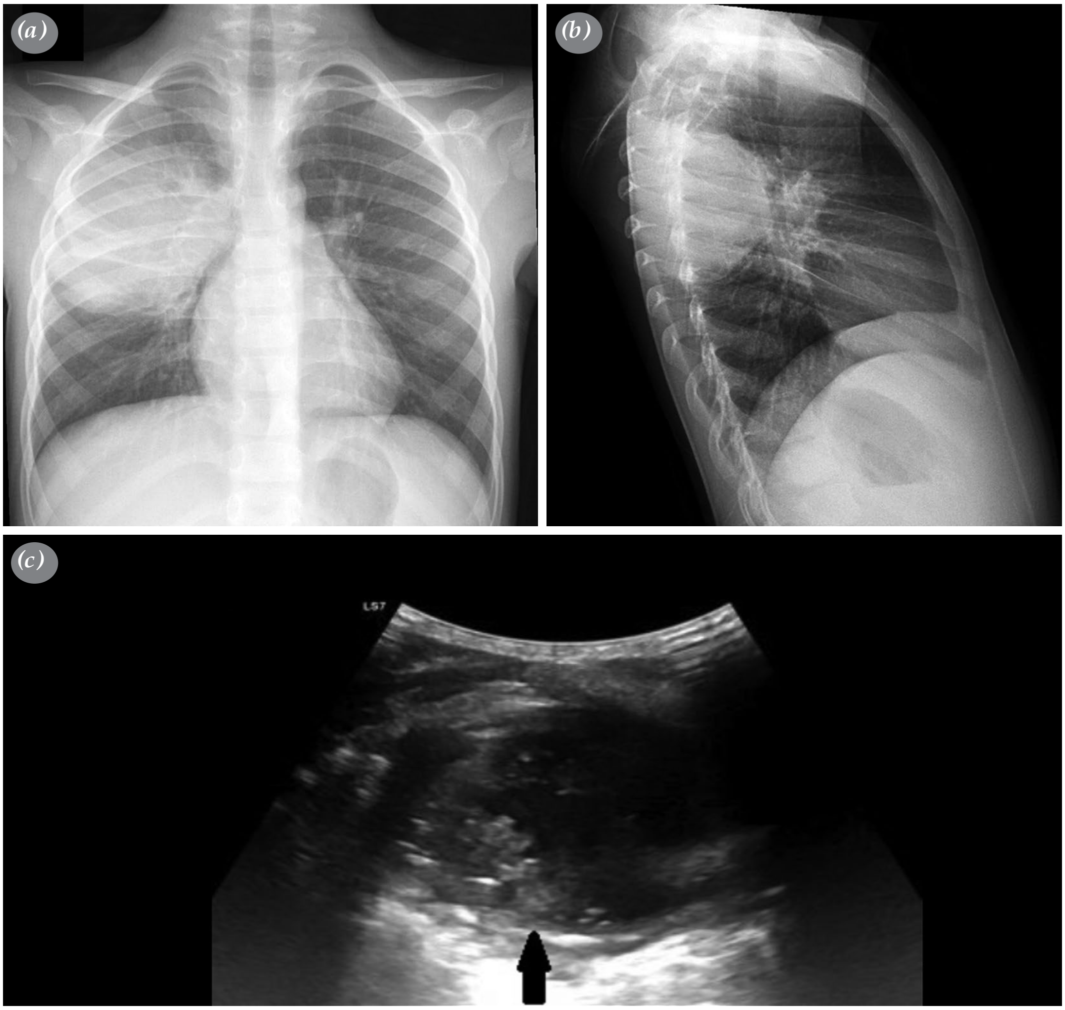

Figure 6. (a, b) Increased opacity with air bronchograms is observed in the upper lobe posterior-lower lobe superior segment of the right lung. The patient expressed pneumonia symptoms, and the appearance was evaluated in favor of round pneumonia. **(c)** The thorax ultrasonography image of the same patient shows that the pleura-based lesion observed in the right lung is an area of pneumonic consolidation containing cystic-necrotic areas. In distinguishing it from a mass lesion using color Doppler ultrasonography, the lesion does not show vascularity or shows very little vascularity in the parenchyma, which is evaluated in favor of necrotizing pneumonia.

arch is suspected. However, on a lateral radiograph, the intrathoracic trachea should have a straight course and not angle forward or backward. During the infantile period, the trachea may collapse during expiration, and this appearance should not be interpreted in favor of tracheomalacia.[6] The right main bronchus is shorter and wider than the left and makes a narrow angle with the trachea; therefore, foreign bodies in children are often directed toward the right main bronchus.

When evaluating diaphragms, one must examine height, contours, and whether there is a difference in level between the two diaphragms. During the neonatal period, the diaphragmatic contours should be evaluated for congenital diaphragmatic hernia. It is an expected finding that the left hemidiaphragm is lower than the right due to the pressure of the heart, but the left hemidiaphragm should never be higher than the right one, and there should be no more than a 3-cm height difference between two hemidiaphragms. In the case of increased diffuse ventilation, both hemidiaphragms flatten, the distance between the ribs widens, and the AP diameter of the chest increases in the lateral radiograph.[7]

In the pediatric age group, bacterial pneumonia is observed as round pneumonia, particularly before the age of eight; therefore, the most common cause of solitary pulmonary nodules in children is round pneumonia. After the age of eight, pneumonia cannot be contained due to the development of Lambert canals and Kohn pores; the infection can spread more easily between segments, and the frequency of lobar pneumonia increases. Clinical information provides valuable guidance when differentiating solitary pulmonary nodules in children. If the clinical symptoms suggest pneumonia, the observed solitary pulmonary nodule on the radiograph could potentially indicate the presence of round pneumonia (Figures 6, 7).[8]

During the assessment of lateral radiography, it is important to consider the significant observation that the opacity of the vertebral bodies progressively diminishes from the top to the bottom, which is commonly referred to as the 'more black sign' or 'spine sign' (Figure 6). The more black sign is a normal finding in lateral chest radiographs and refers to the gradually increasing apparent radiolucency (blackness) of the vertebral bodies when proceeding from upper to lower chest. This is due to the increased

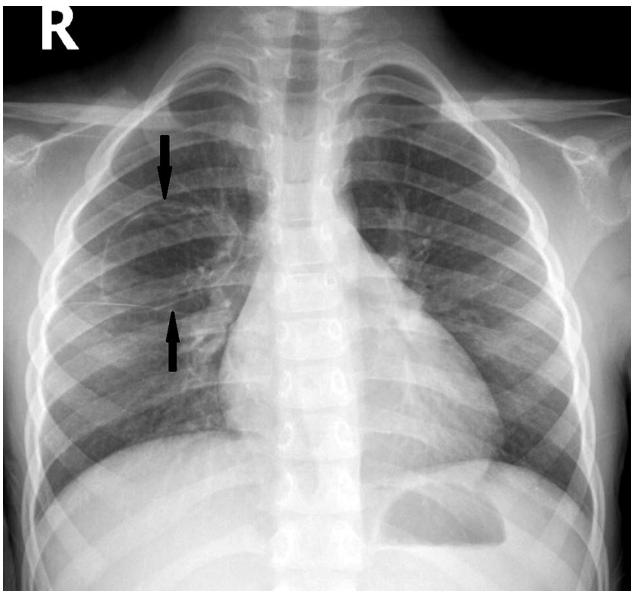

Figure 7. A thin-walled sequela pneumatocele appearance (marked with black arrow) is observed in the radiograph obtained two months after the treatment of the patient shown in Figure 6.

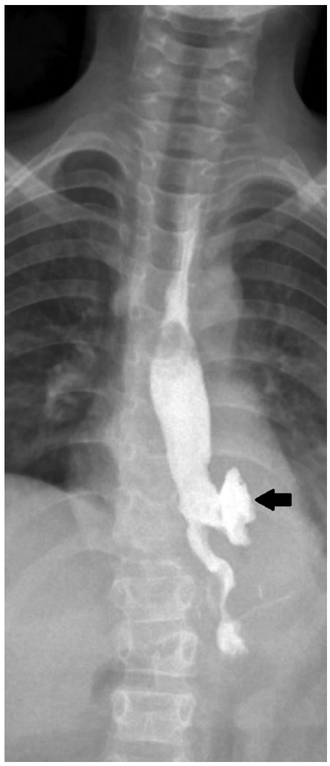
Figure 8. An examination performed by oral administration of iodinated contrast material reveals excess filling with irregular borders, which is compatible with traction diverticulum (marked with black arrow) in the distal part of the esophagus.

proportion of the chest comprised of air-containing lungs over distal dorsal spine compared to the upper parts. If the opacity of a vertebra lower in its course when observed from top to bottom is greater than that of a vertebra above it (i.e., if the latter appears brighter), it suggests the presence of a pathology that increases the opacity of the lower vertebra. This pathology may be a consolidation, infiltration, fluid, or mass lesion.[9]

FLUOROSCOPY

The main indications for fluoroscopy are the evaluation of diaphragm movements and visualization of the gastrointestinal tract. In patients with suspected diaphragmatic eventration or paralysis, a dynamic, real-time examination is performed to evaluate whether the diaphragmatic movements in inspiration and expiration are compatible with the respiratory phase and the presence of paradoxical movements. Currently, motion mode USG is used as an alternative to fluoroscopic examination in the evaluation of diaphragm movements.[10] Dynamic MRI can investigate paralysis, displacement of the diaphragm crura, synchronicity, and speed.[11] Passage is evaluated with radiographs obtained with barium or iodine contrast material in the gastrointestinal tract (Figure 9a). In cases of esophageal atresia and tracheoesophageal fistula, postoperative stenosis, stricture, fistula, and leaks are investigated. At the same time, oral contrast examinations indirectly provide information about vascular anomalies.[12]

ULTRASONOGRAPHY

Ultrasonography is a preferred imaging method in the childhood age group because it lacks ionizing radiation. It is also increasingly used in thorax imaging in daily practice since it is noninvasive, inexpensive, reproducible, easy to apply, and can be performed at the bedside, especially in intensive care units.[13,14] When a hemithorax appears fully opaque on chest radiography, USG can determine whether this opacity is caused by pleural fluid or a lesion in the lung tissue. Ultrasonography can be used to evaluate the content of pleural effusion (Figure 9a), to distinguish between consolidation and atelectasis or masses located close to the chest wall (Figure 6), to evaluate lesions adjacent to the mediastinum, and to distinguish between solid and cystic lesions. Parenchymal edema is increasingly preferred in the diagnosis and differential diagnosis of respiratory distress syndrome and wet lung disease in premature babies and in the evaluation of interstitial diseases.[15] Color Doppler USG provides information about the relationship of lesions with vascular structures and the blood supply in neoplastic lesions, as in cases of pulmonary sequestration.[16] It is used as a guide imaging method in interventional procedures such as thoracentesis.[17] Ultrasonography is also increasingly used in the diagnosis of pneumothorax. Motion mode USG is more valuable than supine radiographs in cases of suspected pneumothorax, especially in intensive care units.[18,19] Knowledge of the normal pleural appearance and movement is necessary to detect possible pneumothorax (Figure 9b). Diaphragmatic movements, paralysis, or eventration can also be evaluated with motion mode USG.[20]

COMPUTED TOMOGRAPHY

In the radiological evaluation of the respiratory system, in cases in which direct radiography and USG cannot be prescribed, CT remains the most used radiological method. Good interpretation of plain

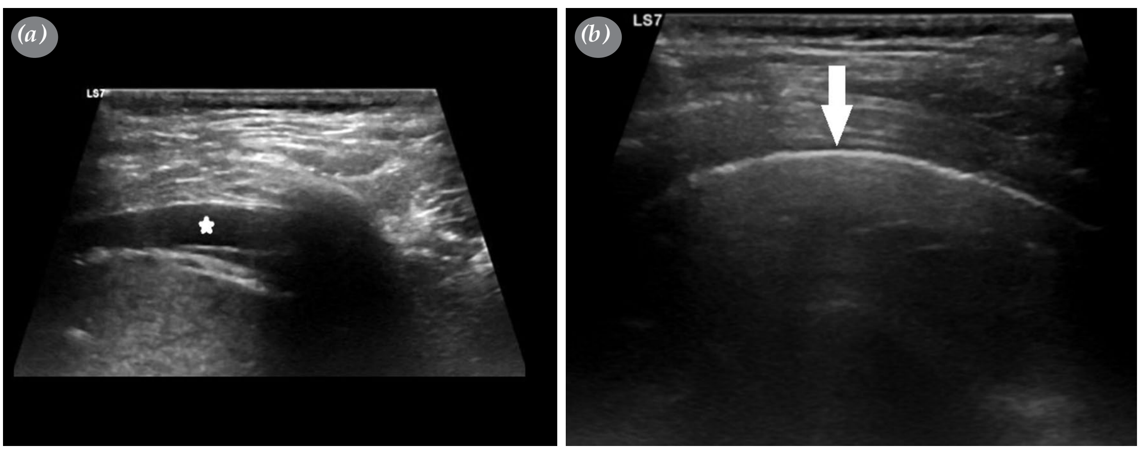

Figure 9. (a) A thorax ultrasonography shows anechoic pleural effusion (starred) with or without internal structure and accompanying passive atelectasis. **(b)** A uniformly hyperechoic image of the pleura, indicated by a white arrow, appears sonographically normal.

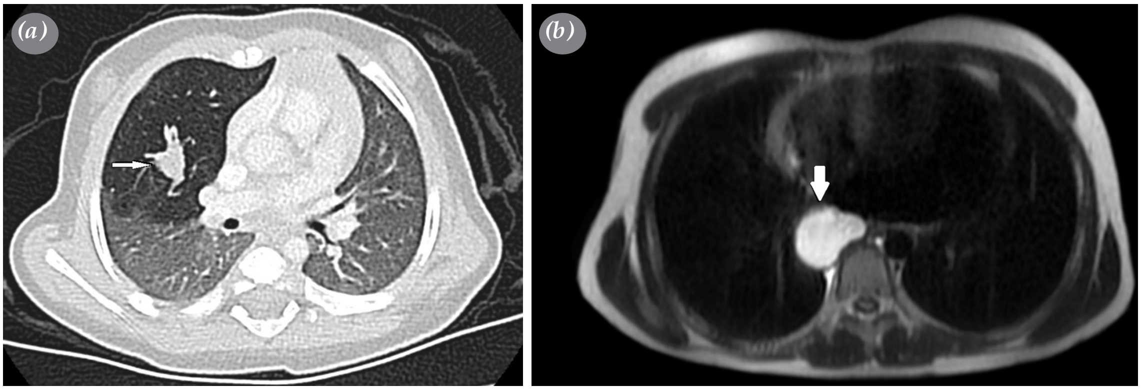

Figure 10. **(a)** A contrast-enhanced thorax computed tomography of a five-month-old female patient reveals hyperinflation in the middle lobe of the right lung and a distinctive glove finger-like appearance, which is marked with a white arrow, indicative of bronchial atresia. **(b)** A 12-year-old patient who was examined for a mediastinal mass (white arrow) shows a cystic lesion with high protein content in the posterior mediastinum.

radiograph findings and a prior preference for USG according to indications can prevent many unnecessary CT examinations. The radiation dose received in a thorax CT examination corresponds to the dose received in approximately 150-200 chest radiographs. Since developing tissues are more susceptible to radiation, it is important to limit CT examinations in childhood to appropriate indications in order to avoid unnecessary exposure to radiation. Radiation dose can be reduced in children by selecting the appropriate tube voltage according to their weight and by using special protocols for children. Computed tomography scans can be performed with or without the use of contrast material, depending on the clinical problem. Precontrast and postcontrast CT applications should not be preferred in children, as they will cause extra radiation exposure.

Multidetector CT shortened examination time and thus reduces artifacts caused by movement and breathing in childhood age group. Multidetector CT can take thin sections in a short time and create three-dimensional reconstruction images. It is also possible to perform virtual bronchoscopy and three-dimensional imaging of the airways. Computed tomography angiography provides more detailed information about vascular structures. The HRCT technique, which uses a section thickness of 1 mm and a gap of 10 mm, is mostly preferred in bronchiectasis, bronchiolitis obliterans, and interstitial lung diseases. Since the HRCT imaging method involves leaving an interval, it should not be used in cases of suspected metastasis. Today, fine collimation (<1 mm) multislice CT can image the entire lung parenchyma without giving additional radiation.[21] Pathologies of the pulmonary vascular bed or aorta are evaluated with CT angiography.

Thoracic CT imaging is utilized in pediatric patients for various indications, including the examination of congenital malformations, evaluation of abnormal chest radiography, investigation of complications related to pneumonia, characterization of lung diseases, identification of mediastinal or enlargement masses, assessment of unidentified lung disease symptoms, determination of the etiology of immunodeficiency fever, screening for metastasis or solitary pulmonary nodules, evaluation of pulmonary embolism, aortic dissection, vascular anomalies, as well as assessment of mediastinal and hilar lymph nodes (Figure 10a).[22]

MAGNETIC RESONANCE IMAGING

Magnetic resonance imaging is increasingly used for imaging the thoracic region, specifically in the childhood age group. The key benefits of this imaging technique include its nonionizing radiation, excellent resolution for soft tissue contrast, and the ability to image in multiple planes. Moreover, the contrast material used with this technique carries a lower risk of allergy and kidney toxicity compared to CT contrast material. However, its use is limited by the long examination time, the need for anesthesia in young children, and the greater incidence of breathing and movement artifacts.

In recent years, faster images have been obtained with parallel imaging methods and multichannel body coils, and MRI is increasingly used in thoracic radiology. Motion artifacts are minimized by methods such as respiratory triggering. Magnetic resonance imaging can characterize the different components in a lesion and investigate the lesion's cellular density, water content, and whether it contains fat (Figure 10b). It is used more frequently in the characterization of mediastinal masses, chest wall lesions, brachial plexus and diaphragm pathologies, and vascular pathologies. The appropriate use of magnetic resonance angiography can reduce the frequency of invasive procedures, such as conventional angiography for diagnostic purposes. Functional imaging of the thorax can be performed with perfusion or ventilation MRI.[23]

ANGIOGRAPHY

In recent years, the widespread use of noninvasive imaging methods, such as CT and magnetic resonance angiography, has significantly reduced the indications for conventional angiography for diagnostic purposes. In pediatric patients, angiography is mostly performed for therapeutic purposes, presurgical vascular tumor embolization, arteriovenous fistula embolization, massive hemoptysis, and vascular stenosis requiring angioplasty.[24]

INTERVENTIONAL PROCEDURES FOR THE THORACAL REGION IN CHILDHOOD

The continuous development of technology and the establishment of interventional radiology as an independent specialty in various regions have led to notable progress in radiological interventional procedures. Radiology has moved into the treatment field with minimally invasive diagnostic and treatment procedures. In interventional radiology, diagnostic and therapeutic procedures are performed for vascular and nonvascular pathologies using catheter-based techniques under the guidance of X-ray (including CT), USG, and MRI. Interventional radiological procedures offer children new treatment options that were not available a few years ago. Interventional radiology requires different skills than diagnostic radiology, and a few pediatric radiologists have received training in interventional radiology.[24]

The main indications of interventional procedures for the thoracic region in children are pleural fluid sampling or therapy; percutaneous transthoracic lung biopsy; bronchial artery embolization in patients with cystic fibrosis and hemoptysis; stent placement in airway obstructions; detection and treatment of complex vascular anomalies or vascular malformations; superior vena cava stenosis and recanalization with balloon angioplasty and stenting in cases of obstruction; placement of central venous catheters, such as permanent catheters and ports in cases requiring long-term medication; placement of a filter in the vena cava to prevent pulmonary embolism in high-risk children; dilatation or stenting in esophageal strictures; and finding lost catheters in the thoracic circulation. The low complication, morbidity, and mortality rates make percutaneous procedures preferable.[24]

PLEURAL FLUID DRAINAGE

Imaging-guided drainage is indicated in empyema, hemothorax, and parapneumonic effusions unresponsive to medical treatment. In children, percutaneously placed thin chest drains with intrapleural fibrinolysis can provide successful drainage in up to 93% of cases, even if the organizing phase of the effusion is incomplete. The main purpose of drainage of a complicated pleural effusion is to control pleural sepsis, ensure expansion of the collapsed-consolidated lung, and prevent chronic complications, such as pleural fibrosis and atelectasis.[24] Providing early drainage before the pleural effusion becomes organized increases the success of treatment.[25] Percutaneous drainage can be performed under sedation or general anesthesia; if the risk of respiratory depression is high, general anesthesia is preferred. For successful drainage, an imaging-guided intervention and optimal positioning of the catheter are required. If the fluid is hemorrhagic, fibrinolytics like urokinase are administered to the pleural cavity for fibrinolysis, thus reducing the viscosity of the pleural fluid; fibrinous septations and adhesions are broken down, and expansion of the underlying lung is achieved. Fibrinolytics are contraindicated if there is active bleeding into the pleural space.

PERCUTANEOUS TRANSTHORACIC BIOPSY

Starting from the infantile age group, lung, pleura, mediastinum, hilus, and chest wall lesions can be sampled with the transthoracic approach.[26] While transthoracic biopsy initially targeted only focal lung lesions, sampling can be performed today via the transthoracic approach for diffuse lung diseases, mediastinal lesions, and pleural lesions. While percutaneous biopsy was previously performed under fluoroscopy guidance, it is now performed under CT or USG guidance. While the modality of choice for biopsy guidance varies depending on the experience of the practitioner, USG is more often preferred since it is faster, cheaper, reliable, and does not contain radiation. For a USG-guided biopsy to be performed, the lesion must be peripherally located and in contact with the pleura. If lung tissue is found between the lesion and the probe, the lesion will not be sonographically visible due to air artifacts, and sampling will not be possible.

Lesions that are not suitable for USG-guided biopsy are sampled with CT guidance. Fluoroscopic scanning is performed with many modern CT devices, and single-slice exposure is performed with a foot pedal, allowing real-time imaging of the lesion. When sampling lesions suspected of lymphoma, percutaneous biopsy may yield an insufficient sample. Sampling of central lesions should be done via a transbronchial approach. Coagulation parameters should be studied before a percutaneous procedure. The most common complication after percutaneous procedures is minor hemorrhage in the center of the lesion, and self-limiting hemoptysis may occur. Major intrathoracic bleeding is encountered in more aggressive sampling from the chest wall or paraspinal lesions. Pneumothorax is observed less frequently in children than in adults; 6 h of observation and direct radiograph control are required for follow-up.[27] Diagnostic procedures for the pulmonary vascular bed have largely been replaced by pulmonary CT angiography, but pulmonary catheter angiography remains the gold standard for imaging and embolization of bronchial arteries in cases of hemoptysis and for the treatment of pulmonary arteriovenous malformations.[28-30]

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REFERENCES

1. Arthur R. Interpretation of the paediatric chest X-ray. Paediatr Respir Rev 2000;1:41-50. doi: 10.1053/prrv.2000.0018.
2. Bansal T, Beese R. Interpreting a chest X-ray. Br J Hosp Med (Lond) 2019;80:C75-9. doi: 10.12968/hmed.2019.80.5.C75.
3. Frush DP, Sorantin E. Radiation use in diagnostic imaging in children: Approaching the value of the pediatric radiology community. Pediatr Radiol 2021;51:532-43. doi: 10.1007/s00247-020-04924-6.
4. Nasseri F, Eftekhari F. Clinical and radiologic review of the normal and abnormal thymus: Pearls and pitfalls. Radiographics 2010;30:413-28. doi: 10.1148/rg.302095131.
5. Marais J, Venkatakrishna SSB, Calle-Toro JS, Goussard P, Eber E, Andronikou S. Patient rotation chest X-rays and the consequences of misinterpretation in paediatric radiology. Paediatr Respir Rev 2023;47:41-50. doi: 10.1016/j.prrv.2023.05.003.
6. Lee EY, Restrepo R, Dillman JR, Ridge CA, Hammer MR, Boiselle PM. Imaging evaluation of pediatric trachea and bronchi: Systematic review and updates. Semin Roentgenol 2012;47:182-96. doi: 10.1053/j.ro.2011.12.002.
7. Kelly B. The chest radiograph. Ulster Med J 2012;81:143-8.
8. Celebi S, Hacimustafaoglu M. Round pneumonia in children. Indian J Pediatr 2008;75:523-5. doi: 10.1007/s12098-008-0085-7.
9. Feigin DS. Lateral chest radiograph a systematic approach. Acad Radiol 2010;17:1560-6. doi: 10.1016/j.acra.2010.07.004.
10. Aljibali AS. Ultrasound utilization in the diagnosis of diaphragm dysfunction compared to other modalities: A retrospective study. Int J Health Sci (Qassim) 2023;17:11-7.
11. Lens E, Gurney-Champion OJ, Tekelenburg DR, van Kesteren Z, Parkes MJ, van Tienhoven G, et al. Abdominal organ motion during inhalation and exhalation breath-holds: Pancreatic motion at different lung volumes compared. Radiother Oncol 2016;121:268-75. doi: 10.1016/j.radonc.2016.09.012.
12. Kir M, Saylam GS, Karadas U, Yilmaz N, Çakmakçi H, Uzuner N, et al. Vascular rings: Presentation, imaging strategies, treatment, and outcome. Pediatr Cardiol 2012;33:607-17. doi: 10.1007/s00246-012-0187-x.
13. Lichtenstein DA. Lung ultrasound in the critically ill. Ann Intensive Care 2014;4:1. doi: 10.1186/2110-5820-4-1.
14. Saraogi A. Lung ultrasound: Present and future. Lung India 2015;32:250-7. doi: 10.4103/0970-2113.156245.
15. Guo BB, Pang L, Yang B, Zhang C, Chen XY, OuYang JB, et al. Lung ultrasound for the diagnosis and management of neonatal respiratory distress syndrome: A minireview. Front Pediatr 2022;10:864911. doi: 10.3389/fped.2022.864911.
16. Gabelloni M, Faggioni L, Accogli S, Aringhieri G, Neri E. Pulmonary sequestration: What the radiologist should know. Clin Imaging 2021;73:61-72. doi: 10.1016/j.clinimag.2020.11.040.
17. Miller A. Practical approach to lung ultrasound. BJA Education 2016;16:39-45. doi: 10.1093/bjaceaccp/mkv012.
18. Ebrahimi A, Yousefifard M, Mohammad Kazemi H, Rasouli HR, Asady H, Moghadas Jafari A, et al. Diagnostic accuracy of chest ultrasonography versus chest radiography for identification of pneumothorax: A systematic review and meta-analysis. Tanaffos 2014;13:29-40.
19. Liu J, Chi JH, Ren XL, Li J, Chen YJ, Lu ZL, et al. Lung ultrasonography to diagnose pneumothorax of the newborn. Am J Emerg Med 2017;35:1298-302. doi: 10.1016/j.ajem.2017.04.001.
20. Boussuges A, Finance J, Chaumet G, Brégeon F. Diaphragmatic motion recorded by M-mode ultrasonography: Limits of normality. ERJ Open Res 2021;7:00714-2020. doi: 10.1183/23120541.00714-2020.
21. Ryu YJ, Kim WS, Choi YH, Cheon JE, Lee SM, Cho HH, et al. Pediatric chest CT: Wide-volume and helical scan modes in 320-MDCT. AJR Am J Roentgenol 2015;205:1315-21. doi: 10.2214/AJR.14.13941.

22. Mordacq C, Deschildre A, Petyt L, Santangelo T, Delvart C, Doan C, et al. Chest computed tomography in children: indications, efficiency and effective dose. Arch Pediatr 2014;21:279-286. doi.org/10.1016/j.arcped.2013.12.021.
23. Sodhi KS. Lung MRI in children: The road less travelled. Indian J Radiol Imaging 2021;31:237-41. doi: 10.1055/s-0041-1729126.
24. Shah JH, Whitmore MJ. Interventional radiology's role in the treatment of pediatric thoracic disease. Semin Roentgenol 2019;54:395-406. doi: 10.1053/j.ro.2019.06.009.
25. Shen KR, Bribriesco A, Crabtree T, Denlinger C, Eby J, Eiken P, et al. The American Association for Thoracic Surgery consensus guidelines for the management of empyema. J Thorac Cardiovasc Surg 2017;153:e129-46. doi: 10.1016/j.jtcvs.2017.01.030.
26. Roebuck DJ, Hogan MJ, Connolly B, McLaren CA. Interventions in the chest in children. Tech Vasc Interv Radiol 2011;14:8-15. doi: 10.1053/j.tvir.2010.07.004.
27. Jarmakani M, Duguay S, Rust K, Conner K, Wagner JM. Ultrasound versus computed tomographic guidance for percutaneous biopsy of chest lesions. J Ultrasound Med 2016;35:1865-72. doi: 10.7863/ultra.15.10029.
28. Zhao QM, Zhao L, He L, Wu L, Lu Y, Chu C, et al. Bronchial artery embolization in pediatric pulmonary hemorrhage: A single-center experience. J Vasc Interv Radiol 2020;31:1103-9. doi: 10.1016/j.jvir.2019.11.007.
29. Wu Z, Lin J, Yang W, Jiang N, Huang N, Clavijo LC. Evaluation of percutaneous transcatheter embolization for pulmonary arteriovenous malformations. BMC Pulm Med 2021;21:77. doi: 10.1186/s12890-021-01448-z.
30. Cusumano LR, Duckwiler GR, Roberts DG, McWilliams JP. Treatment of recurrent pulmonary arteriovenous malformations: Comparison of proximal versus distal embolization technique. Cardiovasc Intervent Radiol 2020;43:29-36. doi: 10.1007/s00270-019-02328-0.