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3RD EDITION

Radiographic Manifestations of Tuberculosis

A PRIMER FOR CLINICIANS ON BASIC RADIOGRAPHY OF PULMONARY TB

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The Curry International Tuberculosis Center (CITC) is a project of the University of California, San Francisco (UCSF) funded by the Centers for Disease Control and Prevention (CDC). The development of *Radiographic Manifestations of Tuberculosis: A Primer for Clinicians on Basic Radiography of Pulmonary TB, 3rd Edition* was funded through Cooperative Agreement NU52PS910247-03.

The first and second editions of this publication were funded through CITC and the Department of Public Health, City and County of San Francisco, with funds awarded under CDC Cooperative Agreement U52CCU900454. Funds were also provided through the National Heart, Lung, and Blood Institute, Tuberculosis Academic Award Program, KO7-HL03057 at UCSF.

Suggested citation:

Curry International Tuberculosis Center, 2025: *Radiographic Manifestations of Tuberculosis: A Primer for Clinicians on Basic Radiography of Pulmonary TB, Third Edition* [inclusive page numbers].

This publication is available on the CITC website: https://www.currytbcenter.ucsf.edu/products/view/radiographic-manifestations-tuberculosis-primer-clinicians-third-edition

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Acknowledgments

The editorial team thanks the following individuals for their assistance and support: **Janice Louie**, MD, MPH, Tuberculosis Prevention and Control, San Francisco Department of Public Health; **Brian Haas**, MD, Department of Radiology and Biomedical Imaging, UCSF; **Gal Tabachnik**, MPH, Curry International Tuberculosis Center, UCSF; **Mari Griffin**, MS, Curry International Tuberculosis Center, UCSF.

Many individuals were involved in the writing, editing, research, and review of the first two editions of *Radiographic Manifestations of Tuberculosis*. The editors of this third edition gratefully acknowledge the ongoing legacy of their contributions.

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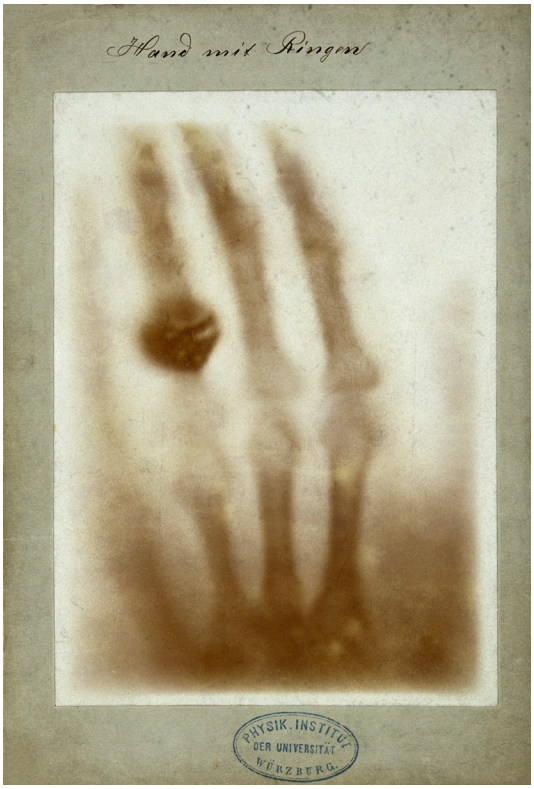
Introduction

Long before the advent of radiography, tuberculosis (TB) was recognized as a disease that predominantly involved the lungs, and a diagnosis of TB was based on a constellation of symptoms and physical examination findings such as rales, rhonchi, and percussion dullness emanating from the lungs. Moreover, the ways in which the lungs were involved and the extent of the involvement could be estimated only by the clinical examination. Obviously, these findings were nonspecific and insensitive; thus, cases were often misdiagnosed, and even correct diagnoses could be stalled until the disease was advanced. Robert Koch's revolutionary discovery of *Mycobacterium tuberculosis* in 1882 provided a test that enabled a specific diagnosis of TB to be confirmed, but it was not widely used for at least several decades after its discovery.

The discovery of x-rays in 1895 by Wilhelm Conrad Röntgen was a second revolutionary development related to TB. Chest radiography greatly reduced both insensitivity and nonspecificity in diagnosing TB and, for the past 130 years, has been a critical tool in the clinical and public health management of the disease. Unfortunately, the coverage of radiographic services remains quite limited in low-resource settings where the prevalence of TB is greatest, although this situation is changing, as will be noted later.



Source: Wikimedia Commons

FIGURE 1.

***Hand mit Ringen* (hand with rings). Print of Wilhelm Röntgen's first "medical" x-ray, of his wife's hand, taken on December 22, 1895.**

Both the discovery of x-rays (documented by Röntgen's famous photo of his wife's hand [Figure 1]) and the very rapid dissemination of the technology were remarkable events. Röntgen's discovery earned him the first Nobel Prize in Physics in 1901, and a flood of scientific papers and books on the topic quickly followed. Many of the publications were technical in nature, while the clinical use of x-ray examinations focused mainly on diagnosing fractures, dislocations, and other bony abnormalities. As other clinical uses were explored, it was soon apparent that radiographic examination of the chest was not only feasible, but would provide more diagnostic information than physical examination, especially as related to TB, an all-too-common disease at the turn of the century.

"The first x-ray machines were large, loud, sparking, smelly, and ostentatious devices, prone to mishap and injury even when fully under the control of the physicians who, in droves, invested money and prestige in them."

Francis H. Williams, MD, a clinician at Boston City Hospital, first reported on use of a fluoroscope to examine the chest in April 1896, a scant 4 months after Röntgen's earthshaking discovery. Due to the long exposure time required to obtain a radiograph, Williams based most of his observations on fluoroscopy, but the findings and principles underlying his observations were equally applicable to both imaging methods.

Dr. Williams went on to articulate several fundamental principles related to thoracic radiology in general and, more specifically, to the use of radiographic examinations for TB (see excerpt on page x). Many of these principles are still relevant today and are embodied in this 3rd edition of *Radiographic Manifestations of Tuberculosis*. In addition, in 1901, Dr. Williams wrote a classic textbook, *The Röentgen Rays in Medicine and Surgery*, one of the first textbooks devoted to radiology. Dr. Williams' most lasting impact was in x-ray examination of the chest, for which he is regarded as a founder of the specialty of thoracic radiology.

During the early 1900s, technical innovations in the science and practice of radiography were evolutionary if not revolutionary. In the words of one medical historian, "The first x-ray machines were large, loud, sparking, smelly, and ostentatious devices, prone to mishap and injury even when fully under the control of the physicians who, in droves, invested money and prestige in them." As implied in the quote, during this time a professional identity for the specialty of "radiology" evolved, despite the drawbacks of the machinery.

X-ray units were rapidly increasing in popularity in the early 1900s, but they were big and cumbersome, a characteristic that limited their use to fixed institutional locations. A fortuitous constellation of events would lead to a major advance in the utility and applicability of radiography. Monico Sanchez Moreno, a brilliant Spanish electrical engineer working in the United States, recognized the need for a more utilitarian x-ray unit. In 1909, Moreno invented a portable machine weighing 22 pounds, as opposed to the nearly 900 pounds that existing units weighed. The unit was marketed as the "Collins Sanchez Portable Device," but it is unclear whether the new device received much attention in either the United States or Europe until World War I.

In the early 1910s, it was clear that a major confrontation was brewing between England and France on one side and Germany on the other. In the run-up to the war, the French government made the seemingly improbable appointment of two-time Nobel Prize winner Marie Curie (Physics,1903 [shared with her husband and Antoine-Henri Becquerel] and Chemistry, 1911) as Director of the Department of Radiology for the French Red Cross. The job required skills in implementation more than inventiveness, and Dr. Curie was more than equal to the task.

With the onset of the war in 1914, Dr. Curie and others quickly recognized that portable units for use in field hospitals could be of great benefit in evaluating war-related injuries and guiding surgical approaches. Consequently, the French government purchased over 50 “Collins Sanchez Portable Devices” and installed them in the ambulances that served the frontlines. Marie Curie grasped the enormous potential for diagnosing wounds on the frontlines and endorsed, extended, and systematized their use. Remarkably, the internationally acclaimed scientist herself drove the portable radiology units (called “petites Curies”) to the frontlines and back, performing x-ray examinations of wounded men along the way (Figure 2).

FIGURE 2. **Marie Curie in a mobile military hospital x-ray unit, circa 1915**

Source: Wikimedia Commons

Dr. Curie’s contributions were not exclusively focused on thoracic radiology, but her implementation of a mobile portable device set the stage for the use of radiography to screen populations for the presence of TB. (The death of Dr. Curie’s mother of TB in 1874 was said to have had a profound effect on the then 7-year-old Marie.)

Also of note, the increased availability of radiography due to Dr. Curie’s implementation skills was not matched by the development of a corps of trained technicians (Dr. Curie herself is said to have taken at least 1,200 radiographs). To remedy this shortage, Dr. Curie developed what was probably the first training program for radiology technicians, a program in which she also taught. Notably, the classes were filled with women, since most men had been drafted into the war.

Even with the success of mobile x-ray units in France and the unfulfilled need for radiographic screening of military recruits for TB in France and the United States, large-scale, population-based screening did not emerge until the early 1940s. The reasons for the slow uptake of radiographic screening for TB included logistic limitations, resistance of physicians to substitute radiography for physical examination, and cost. The affordability of radiographic screening for TB was greatly improved by the development of photofluorography by Brazilian radiologist Manoel de Abreu in 1936. The simple-seeming innovation involved a system that automatically photographed the image on a fluoroscopic screen. Most commonly this produced a 70-mm film image (Figure 3), hence the term “mini mass radiography” (MMR).

FIGURE 3. **70-mm radiographic images from a mass mini photo-fluoroscopy unit**

Source: Freepik

From the 1940s through the 1960s in the United States and other high-income countries, getting an annual chest x-ray in a mobile unit parked in the town square was a common ritual (Figure 4). This practice was discontinued when it became apparent that the cost-per-case identified was exorbitant because the prevalence of TB was rapidly decreasing in high-income countries. How much the annual chest x-rays contributed to the decline in prevalence is unclear. Whether or not routine screening of (presumably) asymptomatic persons is efficient, the finding of a person with previously undiagnosed TB likely had an impact on both personal and public health.

FIGURE 4. **Mobile chest x-ray, circa 1960**

Source: King County, CC BY-NC-ND 2.0

Interestingly, some of the lessons learned from the "chest x-ray in the town square" approach have again become relevant with the development of very compact x-ray units with computer-based interpretation. These innovations have led to a resurgence in interest in radiographic mass population screening in low-income areas of the world where TB is prevalent.

About this book

Radiographic Manifestations of Tuberculosis, 3rd edition, is written primarily for clinicians who are likely to encounter patients with TB, with the clinical use of chest radiography for diagnosis and management of TB in mind. It is not intended to train non-radiologists to provide definitive interpretations of standard thoracic imaging studies. Rather, it serves to indicate when TB should be included in the differential diagnosis of a particular abnormality on a chest radiograph.

In addition, this book provides a common vocabulary to facilitate discussions between clinicians and radiologists. Radiographic imaging is most informative when radiologists and clinicians each bring their unique perspectives and assessments of the image in question to joint discussions. Such discussions result in general agreement on a likely diagnosis and suggest a plan for additional diagnostic tests, especially computed tomographic (CT) imaging and lung or pleural biopsy, if necessary. CT imaging is enormously useful in further elucidating abnormalities seen on the plain chest film and enabling refinement of the differential diagnosis of the finding in question. However, a review of the CT images associated with pulmonary TB is beyond the scope of this book.

The focus of this book is on the use of chest radiography, primarily as a diagnostic tool, generally early in the course of a doctor-patient encounter.

This book is organized so that the reader is presented in Chapter 1 with the radiographic image of the normal thoracic anatomy (as specified by Dr. Williams; see excerpt on page x). The authors have taken great effort to mark and label the structures as clearly as possible, although some features are difficult to discern. An important goal of Chapter 2 is to connect a specific category of abnormality with standard terminology that describes the character of the finding. In Chapter 3 a series of images for the reader to interpret is followed by interpretations and discussions.

The focus of this book is on the use of chest radiography, primarily as a diagnostic tool, generally early in the course of a doctor-patient encounter. An equally important role for radiography is assessing response to treatment. Comparing radiographs over preset intervals or when clinical changes occur provides important information on the effectiveness of therapy. A failure to improve may indicate drug resistance or a wrong diagnosis. Examples of the use of chest radiography to assess response to treatment are included in Chapter 3. Again, as with diagnostic imaging, comparison of images is most informative when clinician and radiologist confer.

As noted, radiography facilities are not widely available in low- and middle-income countries, due to the difficulty of having radiographic equipment and radiologists in low-resource settings. Fortunately, newly developed small portable x-ray units together with computer-assisted interpretation have shown considerable promise for contributing to diagnostic accuracy and for screening populations at risk for TB in low-resource, high-prevalence settings. The role for this technology in diagnostic evaluations in high-resource settings is not yet clear.

The authors have taken pains to use images in which the normal anatomy and abnormalities can be clearly identified, although the print media format of this book does not always lend itself to illustration of subtle findings.

Readers are encouraged to use the book to learn how to better understand the information provided by a chest radiograph and to improve their skills in the diagnosis and management of pulmonary TB.

EXCERPT

The use of radiographic examinations for TB: Fundamental principles

From the 1907 article, *The Use of X-ray Examinations in Pulmonary Tuberculosis*, by Dr. Francis H. Williams

To use the Rontgen rays successfully in practice it is first essential that the physician become familiar with the appearances in the fluoroscope which present themselves in health by examining a number of healthy persons of different weights and ages.

This method (X-ray examination for tuberculosis) may be useful, for example, in:

1. **Making an early diagnosis**
2. **Making precautionary examination where there is possibility that the disease is beginning**
3. **Cases simulating pulmonary tuberculosis**
4. **Determining the extent of the disease**
5. **Determining whether it is diminishing or increasing**
6. **The diagnosis of acute miliary tuberculosis and fibroid tuberculosis**
7. **Recognizing central tuberculosis**
8. **Recognizing sometimes an old tuberculous lesion**
9. **Cases in which emphysema or asthma and pulmonary tuberculosis are associated**
10. **Making an examination for cavities**

Of course, a diagnosis of tuberculosis is not made by the appearances in the fluoroscope alone, they simply indicate an abnormal condition in the lungs.

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Glossary

Terms adapted from *Fleischner Society: Glossary of Terms for Thoracic Imaging (2024)*

Absorption	Pertaining to radiography, absorption is the process of attenuating an x-ray beam. Tissues of different densities transmit numbers of x-ray photons and therefore appear relatively "blacker" (less dense) or "whiter" (denser) on an x-ray film.
Acinar shadow	A round or ovoid, poorly defined pulmonary opacity 4-8 mm in diameter, presumed to represent a pulmonary acinus rendered opaque by consolidation. This term is usually used in the presence of many such opacities.
Air bronchogram	The descriptive term for air-filled airways within partially or completely airless lung parenchyma (whether by virtue of absorption of air or replacement of air or both). The air is visible within the bronchus because the lung surrounding the bronchus is airless. Visualization of an air bronchogram usually implies the presence of an airspace-filling process (consolidation).
Aortopulmonary window	Mediastinal space surrounded anteriorly by the ascending aorta; posteriorly by the descending aorta; superiorly by the aortic arch; inferiorly by the left pulmonary artery; laterally by the left lung; medially by the left aspect of the trachea, left mainstem bronchus, and esophagus, and laterally by the mediastinal pleural covering the left lung. This space normally contains the ligament arteriosum, the left vagus and recurrent laryngeal nerve, lymph nodes, bronchial arteries, and fat and is traversed by the left phrenic nerve.
Atelectasis	Less-than-normal inflation of all or part of a lung with corresponding diminution in volume, often resulting in loss of the normal lucency of the affected portion of lung. Atelectasis manifests on imaging as abnormal fissure, bronchial, and vascular displacement, hyperinflation of adjacent lung, or obscuration of cardiac and mediastinal interfaces.
Attenuation	A collective term for the processes (absorption and scattering) by which the energy of an x-ray beam is diminished in its passage through matter.
Bronchopleural fistula	A direct connection between the pulmonary parenchyma and the pleural space. A bronchopleural fistula is usually manifest on a radiograph as a persistent, often large, pneumothorax, frequently with an air leak when a thoracostomy tube is in place.
Cavitation	The process by which a cavity is formed.

Cavity	A gas-filled space, produced by necrosis of lung tissue and expulsion of the necrotic material via the bronchial tree. An abnormal gas- or fluid-filled structure, isolated, within a zone of pulmonary consolidation, or within a mass or nodule, typically with a thick and often irregular wall. Cavities may or may not contain a fluid level or internal opacity and are characterized with regard to wall thickness and character.
Consolidation	Increased attenuation of lung parenchyma resulting from evacuation of air from the alveoli and replacement by fluid or other material (as in the case of pneumonia). Radiographically, consolidation is seen as a relatively homogeneous opacity in the lung, with effacement of pulmonary blood vessels, little or no volume loss, and sometimes the presence of an air bronchogram.
Cyst	A circumscribed lucent space in the lung, containing gas or liquid whose wall is generally thin and well defined.
Density	Density is a measure of the degree of image darkening (blackness) that reflects the proportion of x-ray photons that are transmitted through the tissue and reach the x-ray detector system. The denser the tissue, the more absorption of the x-ray photons resulting in a whiter image. The less dense the tissue, the blacker the image. In other words, tissues of different density exposed to an x-ray beam produce an image through the process of differential x-ray absorption (see *Differential x-ray absorption*).
Differential x-ray absorption	The process by which different numbers of x-ray photons are attenuated by matter due to differences in the densities of the various components of the matter. When the attenuating matter is human tissue, the process of differential x-ray absorption is responsible for the creation of the radiographic image.
Endobronchial spread	Spread of infected material through the bronchial tree. Radiographically, endobronchial spread often appears as a collection of ill-defined nodules, commonly 4-8 mm in diameter, and often distributed in a segmental or lobar fashion. The nidus of infection, such as a cavity, may be evident. This pattern of disease spread is typical of bacterial causes of infection, including tuberculosis.
Ground glass	An area of increased attenuation that does not completely obscure the underlying bronchial and vascular structures. Compare ground glass with consolidation, in which the underlying anatomic details are completely obscured.
Hematogenous dissemination	Widely but discontinuously distributed throughout an organ or type of tissue. The pattern of hematogenous dissemination is the result of pathology delivered to an organ via the circulation. In the lung the pattern is usually one of well-defined nodules of various sizes distributed throughout the lung, perhaps with a slight basal predominance due to the relatively greater blood flow present in the bases.

Honeycomb pattern	Destruction of lung parenchyma with loss of architecture manifesting as well-defined adjacent cystic structures, typically clustered in the subpleural region, usually accompanied by other findings of fibrosis. The pattern typically presents as one or more layers of thick-walled (2-3 mm) cystic spaces in the peripheral lung, commonly sharing walls, and associated with other findings suggesting fibrotic lung disease, such as traction bronchiectasis and volume loss.
Hydropneumothorax	The presence of both gas and fluid in the pleural cavity.
Interstitium	A continuum of loose connective tissue throughout the lung comprising three subdivisions: the bronchovascular interstitium (surrounding the pulmonary arteries, veins, and bronchi); the parenchymal interstitium (between the alveolar and capillary basement membranes); and the subpleural interstitium (beneath the visceral pleural and within interlobular septa).
Kerley's line (septal line)	Thickening of the interlobular septae in the lung. The interlobular septae are a component of the pulmonary interstitium and represent the margins or walls of the smallest unit of lung structure, known as the secondary pulmonary lobule.
Kerley's A line	A linear opacity 2-6 cm long, obliquely oriented, centrally located, and radiating from the pulmonary hilum, 1 mm or less in thickness. Kerley A lines reflect central interlobular septal thickening.
Kerley's B line	A linear opacity 1-2 cm long and 1-2 mm wide, usually situated in the peripheral and lateral lung base and oriented at right angles to the pleural surface with which it is usually in contact peripherally. Kerley B lines reflect peripheral interlobular septal thickening.
Kerley's C line	Short lines not reaching the pleura (unlike B lines) and not curving obliquely from the hila (unlike A lines). Kerley C lines are also thought to reflect thickened interlobular septae, seen en face, and hence short and not reaching the pleural surface, unlike Kerley B lines.
Lucency	An area of abnormal decreased attenuation, or blackening, on an imaging study reflecting relatively greater x-ray transmission. Examples of lucency in the lung parenchyma include emphysema, cysts, and cavities.
Lymphadenopathy	Abnormal lymph node enlargement. While some may consider this term to also encompass an abnormal increase in number of lymph nodes or abnormal internal lymph node architecture (such as necrosis), the normal allowable number of lymph nodes in a given location is not standardized. The internal architecture of lymph nodes is generally not assessable on chest radiography (except the presence of calcification); thus, the term lymphadenopathy is best reserved for indicating abnormal lymph node enlargement.

Mass	A circumscribed lesion, typically a soft tissue structure (although cavitary, cystic, or calcified constituents may be present to various degrees) greater than 30 mm in diameter. Like nodules (see *Nodule*), masses should be characterized with regard to size, shape, attenuation, and margin characteristics.
Miliary pattern	Diffusely and randomly distributed nodules 1-2 mm in size, the size of millet seeds. The miliary pattern commonly reflects hematogenous spread of a process to the lungs; such processes commonly include infections (particularly mycobacterial and fungal) and metastatic disease.
Nodule	A circumscribed, round or oval pulmonary opacity, less than or equal to 30 mm in average diameter. Like masses (see *Mass*), pulmonary nodules should be characterized with regard to size, shape, attenuation, and margin characteristics.
Opacity	Any focal or diffuse nonspecific area of increased attenuation. Opacity is now preferred over the obsolete term “infiltrate.”
Parenchyma	The functional tissue of an organ; in the case of the lung, the tissue responsible for gas exchange.
Photon	In physics, a corpuscle of energy or particle, a quantum of light or other electromagnetic radiation (e.g., x-rays).
Pleural thickening	An increase in thickness of the pleura, usually resulting from prior inflammation with subsequent fibrosis or tumor. The presence of pleural thickening may be suggested when pleural opacity is stable for long periods of time on serial radiographs (usually over a period of months or years) or when the pleural opacity fails to demonstrate mobility on decubitus radiographs. Note that in the latter circumstance, loculated pleural fluid collections may behave similarly, thus the lack of mobility of a pleural opacity with decubitus radiographs is not pathognomonic for pleural thickening.
Post-primary tuberculosis (reactivation tuberculosis)	The development of tuberculosis one or more years after initial infection, usually appearing as areas of increased opacity in the upper lobes, often with cavitation.
Primary tuberculosis	The initial *Mycobacterium tuberculos*is infection in a previously uninfected individual. Primary tuberculosis commonly manifests on chest radiographs as mid- and lower-lung opacities often associated with hilar and mediastinal lymphadenopathy.
Reticular pattern (reticulation)	A collection of innumerable small linear opacities that together produce the appearance of a net.

Reticulonodular pattern	A collection of innumerable small linear and small nodular opacities that together produce a composite appearance resembling a net with small, superimposed nodules. The linear and nodular elements are usually similar in magnitude.
Retrosternal clear space	The lung parenchyma visible on the lateral radiograph posterior to the sternum. Usually only a few pulmonary blood vessels are visible in this region.
Right paratracheal stripe	A vertically-oriented linear opacity 2-3 mm wide that extends from the thoracic inlet to the right tracheobronchial angle on the frontal radiograph. It is situated between the air shadow of the trachea and the right lung and is formed by the right wall of the trachea and contiguous mediastinal tissue and adjacent pleura.
Scatter	Pertaining to radiography, scatter refers to radiation that enters a patient and is deflected from its initial course but may still contact and expose the x-ray film. Scatter radiation contributes to the patient radiation dose and degrades the radiographic image.
Septal line	A generic term for fine linear opacities of varied distribution produced by the interstitium between pulmonary lobules when the interstitium is thickened by fluid, dust deposition, cellular material, etc. See also *Kerley's line*.
Silhouette sign	The effacement of a normally visualized contour that was created by the juxtaposition of structures with different radiographic densities (e.g., soft tissue contacting air). When two adjacent structures that differ in density are altered in such a way that both structures become the same density, as occurs when normally aerated lung becomes consolidated, the normally visual contour at the interface of these structures will no longer be visualized.
Stripe	An extended, longitudinal, composite opacity 2-5 mm wide, used as a descriptor of shadows created by mediastinal structures.
Unabsorbed	Pertaining to radiography, unabsorbed refers to that portion of the x-ray beam that traverses the patient and does not interact with the patient's tissues. These x-ray photons pass through the patient unaffected and expose the x-ray film, thereby contributing to the creation of the radiographic image.

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