CHEST

Reducing Errors Resulting From Commonly Missed Chest Radiography Findings

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Chest radiography (CXR), the most frequently performed imaging examination, is vulnerable to interpretation errors resulting from commonly missed findings. Methods to reduce these errors are presented. A practical approach using a systematic and comprehensive visual search strategy is described. The use of a checklist for quality control in the interpretation of CXR images is proposed to avoid overlooking commonly missed findings of clinical importance. Artificial intelligence is among the emerging and promising methods to enhance detection of CXR abnormalities. Despite their potential adverse consequences, errors offer opportunities for continued education and quality improvements in patient care, if managed within a just, supportive culture.

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KEY WORDS: artificial intelligence; chest radiograph; education; errors; misses

An expert is someone who knows some of the worst mistakes that can be made in his subject, and how to avoid them. —Werner Heisenberg

The only real mistake is the one from which we learn nothing. —Henry Ford

The interpretation of chest radiography (CXR), the most frequently performed imaging examination, is prone to errors resulting from missed findings. The most commonly missed findings, the major causes of these errors, and their potential adverse consequences have been reviewed recently by the authors.[1] Herein, we present strategies clinicians can implement to help avoid overlooking commonly missed CXR findings. Important among these approaches is a consistent, systematic, and comprehensive visual search pattern, paying particular attention to known blind spots (Fig 1). To achieve this, a practical CXR interpretation scheme is offered. In addition, the potential use of a checklist is proposed and illustrated. Such a checklist can be integrated into the interpretation scheme. Technical advances that can augment the visibility and detection of these commonly missed findings are discussed. These include bone suppression and the rapidly emerging use of artificial intelligence (AI) algorithms.

Although computers will play an increasing role, CXR interpretation remains a human process for the foreseeable future, and thus vulnerable to human error. Because these errors are inevitable, an essential component of error reduction strategies is promoting a nonpunitive, just culture. The latter

ABBREVIATIONS: AI = artificial intelligence; CXR = chest radiography

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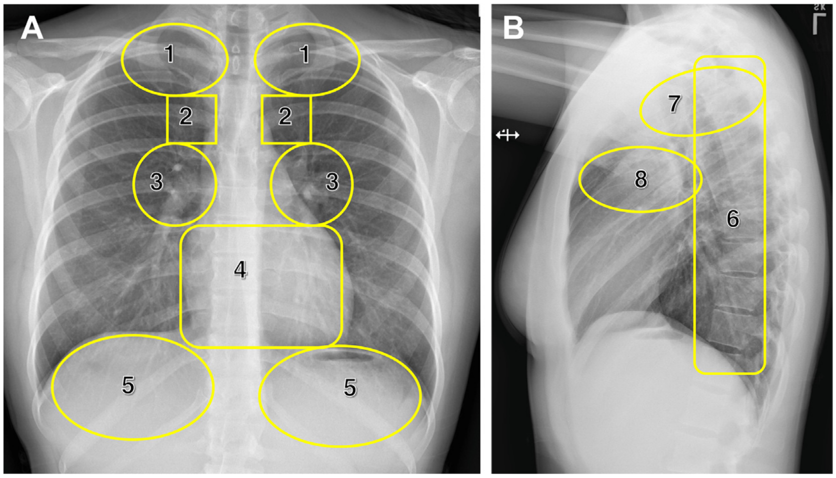

Figure 1 – *Be aware of the common locations of missed pulmonary nodules, the so-called blind spots. A, On posteroanterior chest radiography (CXR) view, these include: (1) lung apices, in areas surrounded by the first ribs; (2) juxtamediastinal regions between the apices and hila; (3) hilar regions; (4) retrocardiac areas; and (5) lung areas projected beneath the diaphragms. B, On lateral CXR view, these include: (6) lung overlying the lateral spine, (7) posterior and apical upper lobes, and (8) lung superimposed on the superior heart. (Reprinted with permission from Gefter et al.[1])*

recognizes that errors provide opportunities for ongoing education and improved quality of patient care. Such opportunities are described.

Approaches to Reducing Errors Resulting From Missed CXR Findings

The major approaches to reducing errors resulting from missed CXR findings are shown diagrammatically in Figure 2. These approaches are shown in the context of the sequential steps in the performance of CXR and interpretation of its results. Methods to mitigate perceptual errors are emphasized because these are the dominant source of missed findings. No single approach may be sufficient, and therefore multiple methods can be combined.

Optimizing CXR Image Quality

Proper technique in acquiring and displaying CXR images is mandatory; otherwise, abnormalities may be missed.[2] Clinicians interpreting CXR images should make note of deficiencies in image quality that may affect lesion detection adversely. As an example, low kVp can fail to display 30% or more of the lungs (in hidden areas). Scatter filtering devices can reduce noise from scatter radiation, which decreases contrast and visualization of small, low-density lesions such as subsolid lung nodules. Quality assuarance processes should be in place to assure that image acquisition and display parameters are in compliance with established performance standards. From a practical standpoint, visibility of the endplates of vertebral bodies through the cardiac shadow is one indication of correct exposure factors (Fig 3). Proper patient centering and positioning are important; otherwise, portions of the lungs are obscured.[2] For example, the scapulae should be positioned so as not to be superimposed over the lungs. The CXR images should be acquired during a breath hold at full inspiration, allowing visualization of the lung bases

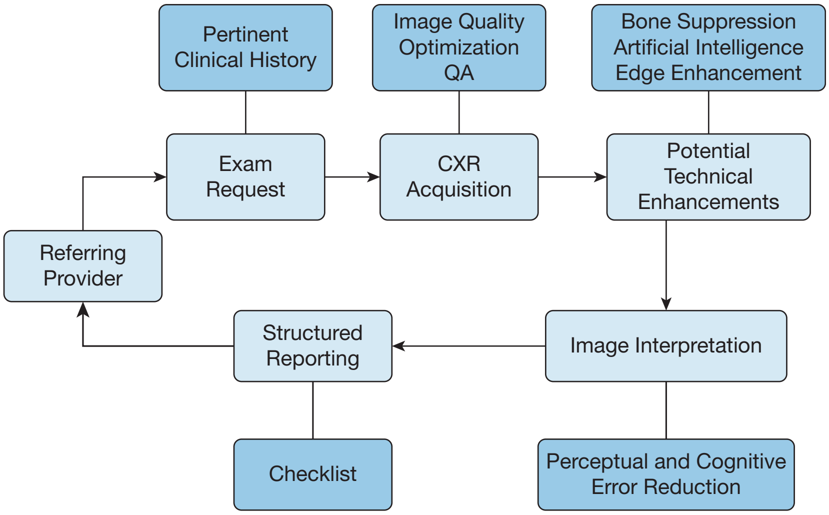

Figure 2 – *Flow diagram showing major approaches to CXR error reduction (blue boxes) shown diagrammatically in the context of steps in the performance and interpretation of the CXR image (gray boxes). CXR = chest radiography.*

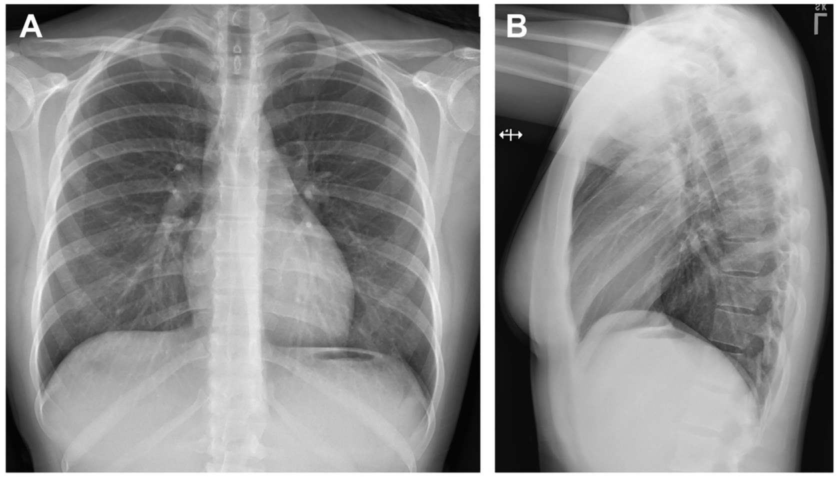

Figure 3 – *A, B, Chest radiographs from a 19-y-old woman showing normal findings on posteroanterior (A) and lateral (B) views.*

(Fig 3). Shallow inspiration may hide or create the appearance of nodules, may mimic congestive heart failure or interstitial lung disease, and may obscure small pleural effusions.[2]

Digital CXR, the current standard, requires processing of the raw digital pixel values to create the final grayscale image. Suboptimal processing can diminish lesion conspicuity or can mimic lesions. This processing aims to increase visibility of opaque regions (mediastinum, retrocardiac, diaphragms) without compromising contrast or detail in the lungs (Fig 3).[3]

The performance metrics of monitors displaying the CXR images also impact the clarity of the images. These include their spatial resolution, luminance, uniformity, and grayscale range.[2,4] The monitor characteristics should conform to established performance standards.[5,6] Otherwise, low-contrast abnormalities (ground-glass nodules and other pulmonary opacities) may be obscured. This is especially important with increased remote reading, as has occurred during the COVID-19 pandemic.

Optimizing Image Interpretation

Understanding the potential causes of missed CXR findings can be used to implement methods to mitigate them. These include the following.

Optimal CXR Viewing Conditions: Suboptimal ambient lighting, background noise, and other distractions, interruptions, excessive CXR reading speed, and fatigue all may contribute to errors in CXR interpretation. Regarding fatigue, studies have shown that radiologists' accuracy decreases after 8 h in the reading room.[7]

Systematic, Consistent and Comprehensive Visual Search Pattern and Deliberate Attention to Blind Spots: Abnormal CXR findings cannot be detected if they are not included within the visual search path.

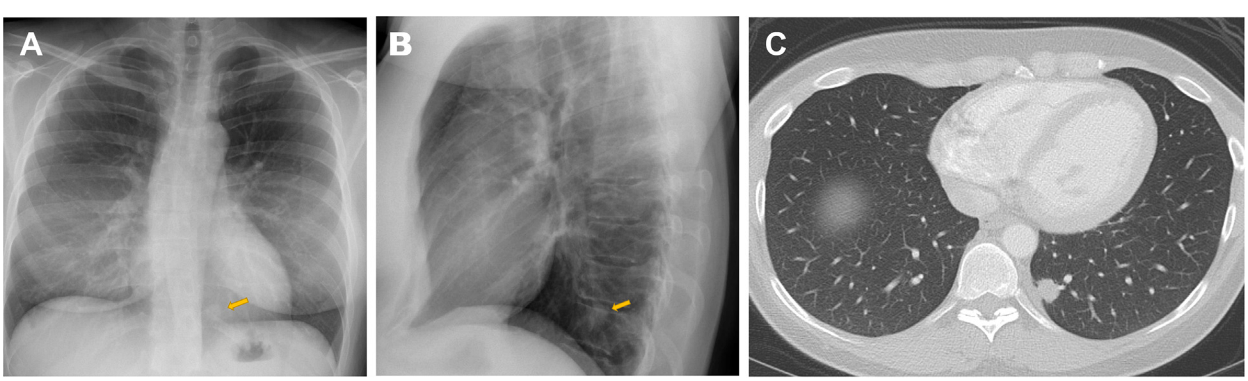

Figure 4 – *A-C, Images from a 34-y-old woman with a small pulmonary nodule in the left lower lobe. A, Posteroanterior chest radiograph showing a nodular opacity superimposed on the inferior heart just above the medial left hemidiaphragm (arrow). The nodule is located within one of the blind spots in which lung nodules commonly are missed (see Fig 1). B, Lateral chest radiograph showing the nodule overlying the lower thoracic spine (arrow). C, Axial noncontrast CT scan demonstrating the corresponding lobulated nodule with pleural indentation in the left lower lobe. (Reprinted with permission from Gefter et al.[1])*

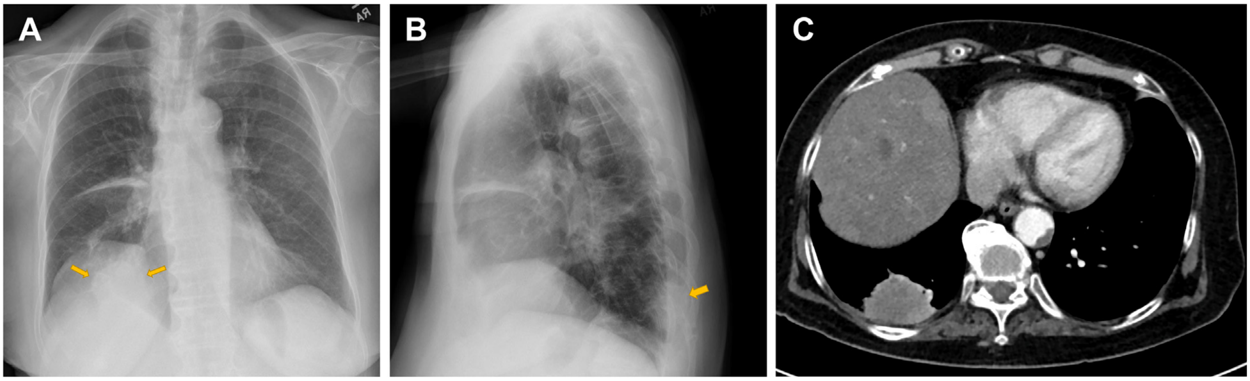

Figure 5 – *A-C, Images from an 82-y-old woman with right lower lobe non-small cell lung cancer. A, Posteroanterior chest radiograph showing a round opacity at the right lung base, superimposed on the right hemidiaphragm (arrows). The lesion may be missed easily without attention to the blind spots in the lungs. B, Lateral chest radiograph showing the opacity overlying the mid to lower thoracic spine (arrow). C, Axial CT scan with contrast enhancement demonstrating the corresponding mass in the right lower lobe abutting the pleura. Multiple liver metastases also are seen. (Reprinted with permission from Gefter et al.[1])*

Regardless of how global or sequential the search trajectory, focused attention to known blind spots is essential. A logical and comprehensive search strategy to reduce the risk of overlooking commonly missed CXR features is offered herein (see "A Practical Scheme for Interpreting CXR Images and Reducing Error").

Importance of the Lateral Radiograph: Standard, nonportable CXR generally includes both posteroanterior and lateral views (Fig 3). The importance of the lateral radiograph cannot be overemphasized. Although approximately 85% of the lungs are visible on the posteroanterior view,[8] lesions obscured on the posteroanterior may be visible on the lateral view (Figs 4-7). These include nodules and pneumonia in the blind spot regions or that are obscured by overlying ribs, clavicle, or pulmonary vessels. In particular, opacities at the lung bases may be visible on the lateral view only.[2] Likewise, small effusions may be detectable only on the lateral view. The lateral view also is useful to evaluate questionable pulmonary lesions on the posteroanterior view, hilar (Fig 8) and mediastinal abnormalities, and lesions of the thoracic spine and sternum.

Avoidance of Satisfaction of Search and Inattentional Blindness: A common tendency is to abort or limit visual search after an abnormality is detected. This so-called satisfaction of search must be consciously avoided. Another source of missed findings is referred to as *inattentional blindness*. In this perceptual error, an abnormality is looked at directly, but is not seen because attention is focused on another search task. This was demonstrated dramatically in a study in which 83% of expert radiologists failed to see a prominent image of a gorilla inserted into a chest CT scan because they were searching for lung nodules.[9] Although difficult to overcome, this phenomenon emphasizes the need for undivided attention during CXR interpretation.

Comparison With Available Prior Studies (CXR and Chest CT Scan Images)

Comparison with prior CXR images not only provides important information on interval changes in an abnormality, but also increases sensitivity in the detection of subtle lesions (Fig 8). This is the basis for temporal subtraction software. Review of prior chest CT scans, when available, can enable identification of findings that otherwise may be missed on CXR.

Review of Pertinent Clinical History

An important objective of CXR interpretation is addressing the clinical indication for the study. Clinical history can guide visual search, attention, and decision-making. A study evaluating the impact of clinical history on the accuracy of CXR interpretation showed that it increased accuracy from 16% to 72% among trainees and from 38% to 84% among experienced readers.[10] However, clinical history potentially can have the opposite effect by misdirecting search,[11] biasing expectations of findings, and risking inattentional blindness. Thus, reviewing the CXR first without and then with the clinical history has been a recommended strategy.

Avoidance of Cognitive Biases

Image interpretation is vulnerable to both cognitive as well as perceptual errors. The cognitive errors largely are the result of many types of bias that influence whether

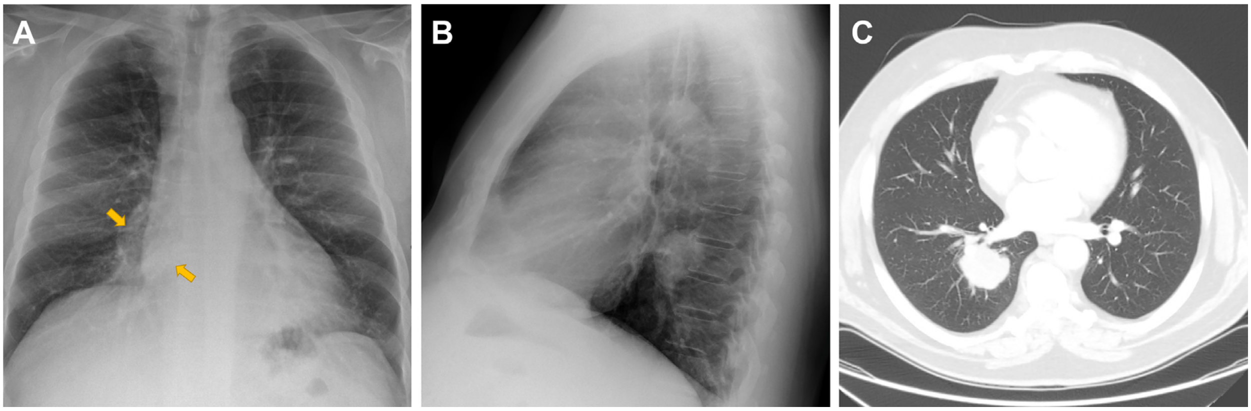

Figure 6 – *A-C, Images from a 56-y-old man with right lower lobe non-small cell lung cancer. A, Posteroanterior chest radiograph showing an opacity at the medial right lung base, superimposed on the right heart and the right descending pulmonary artery (arrows). B, Lateral chest radiograph showing this opacity more clearly visualized anterior to the lower thoracic spine. C, Axial CT scan demonstrating the corresponding mass in the right lower lobe. (Reprinted with permission from Gefter et al.[1])*

CXR findings are recognized. Potential solutions to cognitive errors are: (1) metacognition,[12] in which the individual interpreting the CXR image actively thinks about how conclusions are being reached; and (2) debiasing,[13] in which the CXR reader maintains awareness of common cognitive biases and actively avoids them.

Technical Enhancements: Bone Suppression and AI

CXR images, being digital, can be processed further using algorithms to increase the conspicuity of parenchymal lung lesions. Bone suppression software, most recently using machine learning-based algorithms, can remove the density of overlying ribs and clavicles, which otherwise would obscure lung lesions, including nodules, TB, and pneumonia (Fig 9). Bone suppression is particularly useful for improved detection of lung cancers and TB, which commonly are located in the apices and hidden by the clavicles, first ribs, and their costochondral junctions. Temporal subtraction software can highlight areas of change from older radiographs, but has not been used widely because of marked differences in positioning and lung volumes on serial CXR images.

The use of AI, primarily using deep learning with convolutional neural networks, is a rapidly emerging and highly promising approach to reducing missed CXR findings (Figs 10-12). The large volume of CXR images obtained, the complexity of their interpretation, and their value in clinical practice have been an impetus for using AI to increase CXR interpretation accuracy and efficiency.[14,15] Among the goals of AI are to assist the

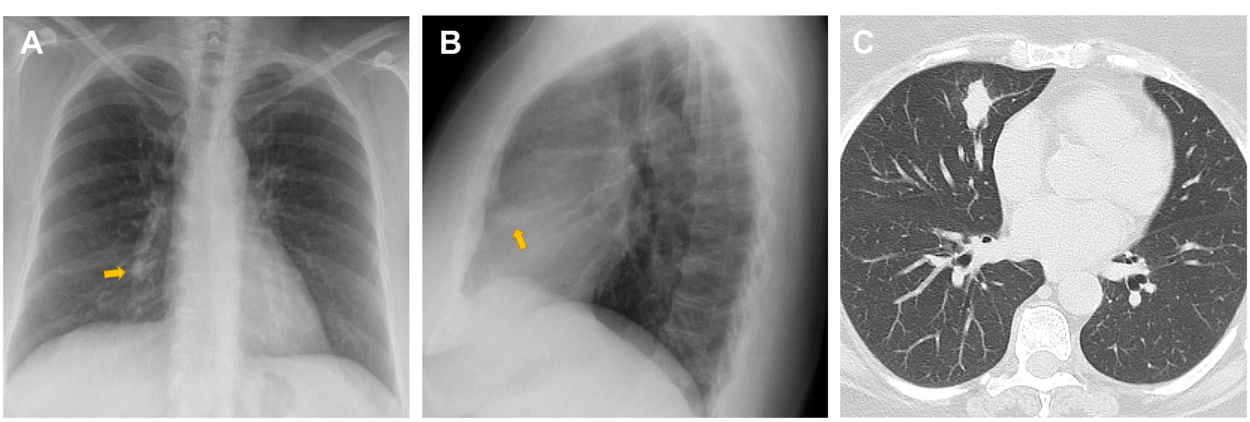

Figure 7 – *A-C, Images from A 62-y-old woman with carcinoid tumor in the right middle lobe. A, Posteroanterior chest radiograph showing a subtle asymmetric opacity superimposed on the mid portion of the right descending pulmonary artery (arrow). B, Lateral chest radiograph showing the nodule to better advantage anteriorly in the right middle lobe (arrow). C, Axial noncontrast CT scan demonstrating the corresponding lobulated lesion in the right middle lobe. (Reprinted with permission from Gefter et al.[1])*

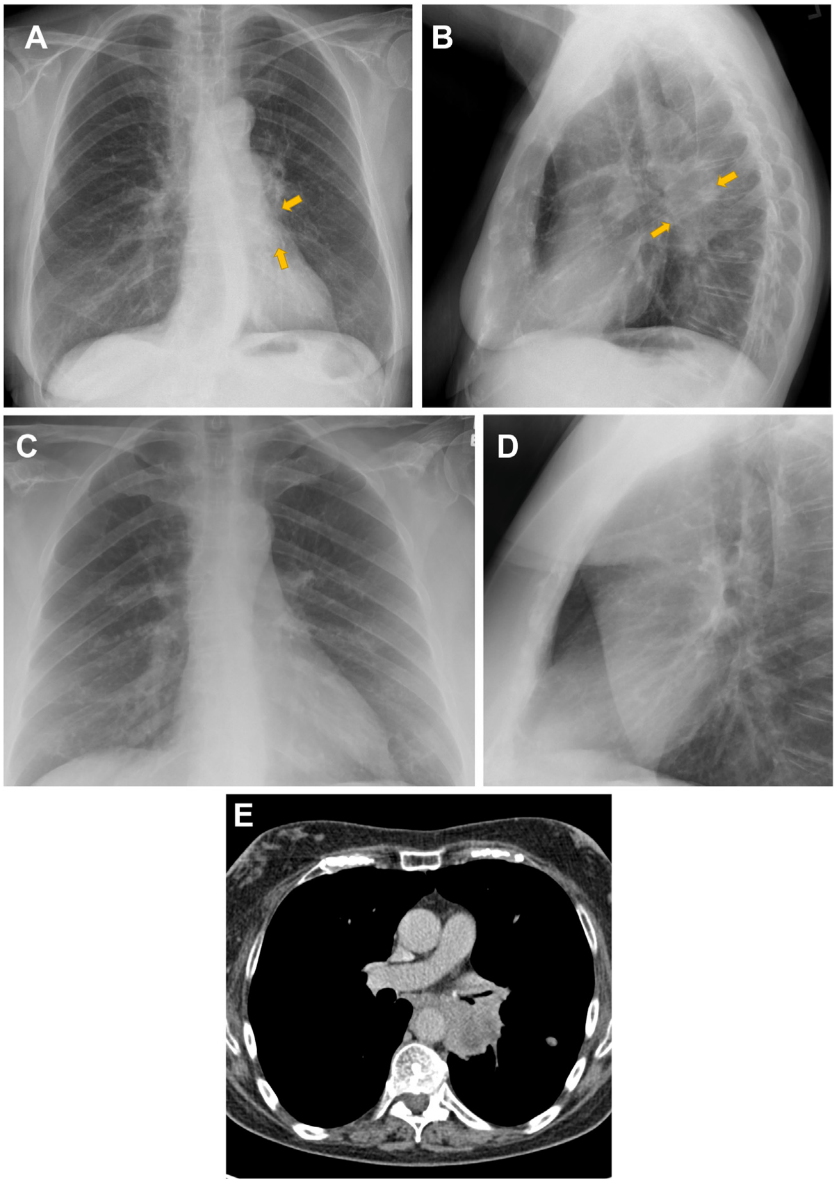

Figure 8 – *A-E, Images from a 58-y-old woman with left lower lobe non-small cell lung cancer. A, Posteroanterior chest radiograph showing subtle increased opacity in the left infrahilar area (arrows). B, Lateral chest radiograph showing the corresponding opacity anterior to the mid thoracic spine (arrows). C, D, Posteroanterior and lateral chest radiographs showing that the abnormality is more easily identified when compared with the prior posteroanterior and lateral chest radiographs. E, Axial contrast-enhanced CT scan demonstrating the corresponding hilar mass with heterogenous enhancement in the left lower lobe. This case illustrates the importance of comparison with prior radiographs and that even large masses in the hilar region may be difficult to detect. Knowledge of normal hilar anatomy is essential. (Reprinted with permission from Gefter et al.[1])*

reader in the detection of subtle findings to avoid misses, to separate normal from abnormal CXR findings rapidly, and to provide radiologic expertise in settings in which this is not available.[14,16-18]

Investigational studies have shown that AI performance is comparable with or exceeds that of expert readers for detecting specific CXR abnormalities.[15,19] AI potentially can be deployed as a first, second, or concomitant reader.[20,21] The synergistic combination of AI together with a human reader is a promising optimal approach to increased CXR interpretation accuracy and error reduction. AI combined with radiologists has been shown to decrease average missed lung cancers by 60% as well as to improve radiologist interreader variability.[15] AI potentially can overcome some of the common sources of human errors because it is not susceptible to distractions, incomplete search, fatigue, and so forth.

However, many ongoing challenges exist in developing, validating, and deploying these AI algorithms. Large, well-labelled, nonbiased, and anonymized datasets are required for training and validation. The algorithms need to be widely generalizable to assure robustness to different geographic populations with varying prevalence of diseases, different CXR equipment, and different acquisition parameters. The output from black box algorithms needs to be explainable. Furthermore, the algorithms will need to incorporate clinical as well as

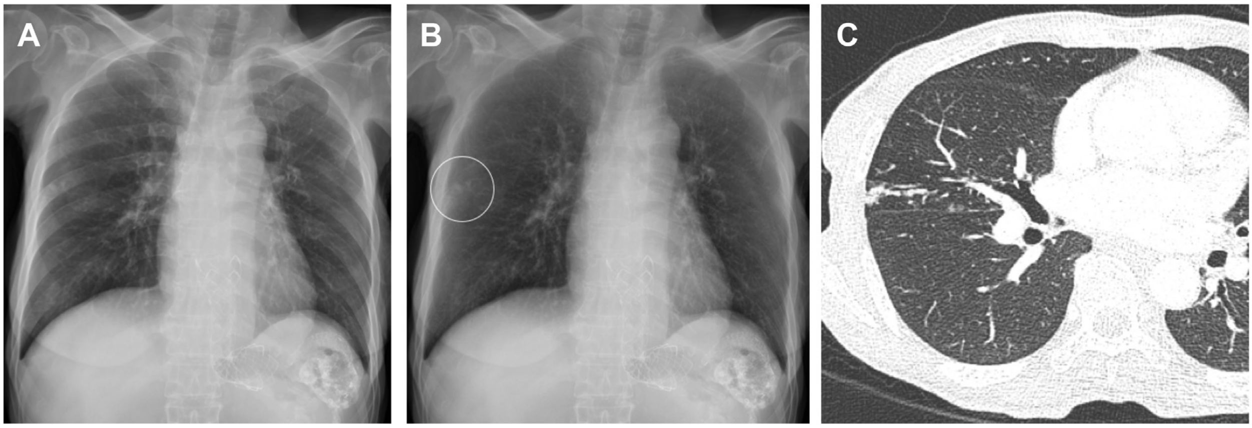

Figure 9 – *A-C, Images from a 64-y-old woman with a diagnosis of tuberculosis. A, Chest radiograph showing suspicious nodular opacities in the right middle lung area. These are partially obscured by the superimposed rib. B, Software-based bone suppression image clearly showing multiple clustered nodules in the corresponding area (circle). C, CT scan also showing multiple centrilobular nodules in the right middle lobe, which were confirmed as tuberculosis. (Courtesy of Drs Joon Beom Seo and Gil-Sun Hong, Asan Medical Center, Seoul, South Korea.)*

imaging data and to be integrated nondisruptively into routine workflow. Another advantage of CXR being digital is the ability to include additional processing techniques, such as edge enhancement, to increase the conspicuity of pneumothoraces and lines or tubes. The major sources of errors and corresponding error mitigation strategies are summarized in Table 1.

A Practical Scheme for Interpreting CXR Images and Reducing Error

Given the large number of CXR studies performed and the risks of errors resulting from missed findings, proficiency in their interpretation continues to be essential.[22] Guided by knowledge of the sources of error and methods to avoid overlooking commonly missed, clinically relevant findings, the following practical scheme for CXR interpretation can be suggested (Table 2). The sequence of search steps may be modified according to individual preference. However, it is recommended that each clinician interpreting CXR images develop a consistent, systematic, and comprehensive routine for examining the images. Although efficiency and speed undoubtedly increase with experience, no essential component should be omitted.

Preliminary Observations

The patient name, age, sex, examination date, the presence of a lateral radiograph and prior chest imaging studies for comparison may be checked quickly. Any limitations in image quality should be noted. The CXR image may be viewed first without clinical history to eliminate any perceptual or cognitive biases, after which the radiograph can be reviewed in light of the history and to address specific clinical questions. Initially, one should look at the CXR images globally. In doing so, the overall lung volumes can be assessed, and any asymmetries or obvious abnormalities in the chest may be evident at a glance.

The Lungs: Next, each lung should be scanned completely, from apex to below the domes of the diaphragms. In addition, scanning across both lungs horizontally enhances detection of asymmetries, increasing the conspicuity of pulmonary nodules and other parenchymal opacities. The dark areas of the lung apices encompassed by the first ribs should be symmetric bilaterally. Attention should be paid to areas of the lung that may be obscured partially by overlying ribs and clavicles. A deliberate second visual scan should be made through the known lung blind spots, illustrated in Figure 1.

The normal density over the heart is approximately half that over the liver in the right upper quadrant of the abdomen. Behind the heart lie the left and right lower lobes, where an abnormal increased focal opacity may be observed on the posteroanterior radiograph as an area with a density intermediate between that of the heart and the liver. It is important to remember that the medial border of the right lung extends in front of the thoracic spine as the azygoesophageal recess. The lower lobes extend inferiorly and posteriorly from the top of the hemidiaphragms, which increase gradually in density on the posteroanterior radiograph.

It is important to scrutinize the lungs on the lateral radiograph when acquired, with particular attention to

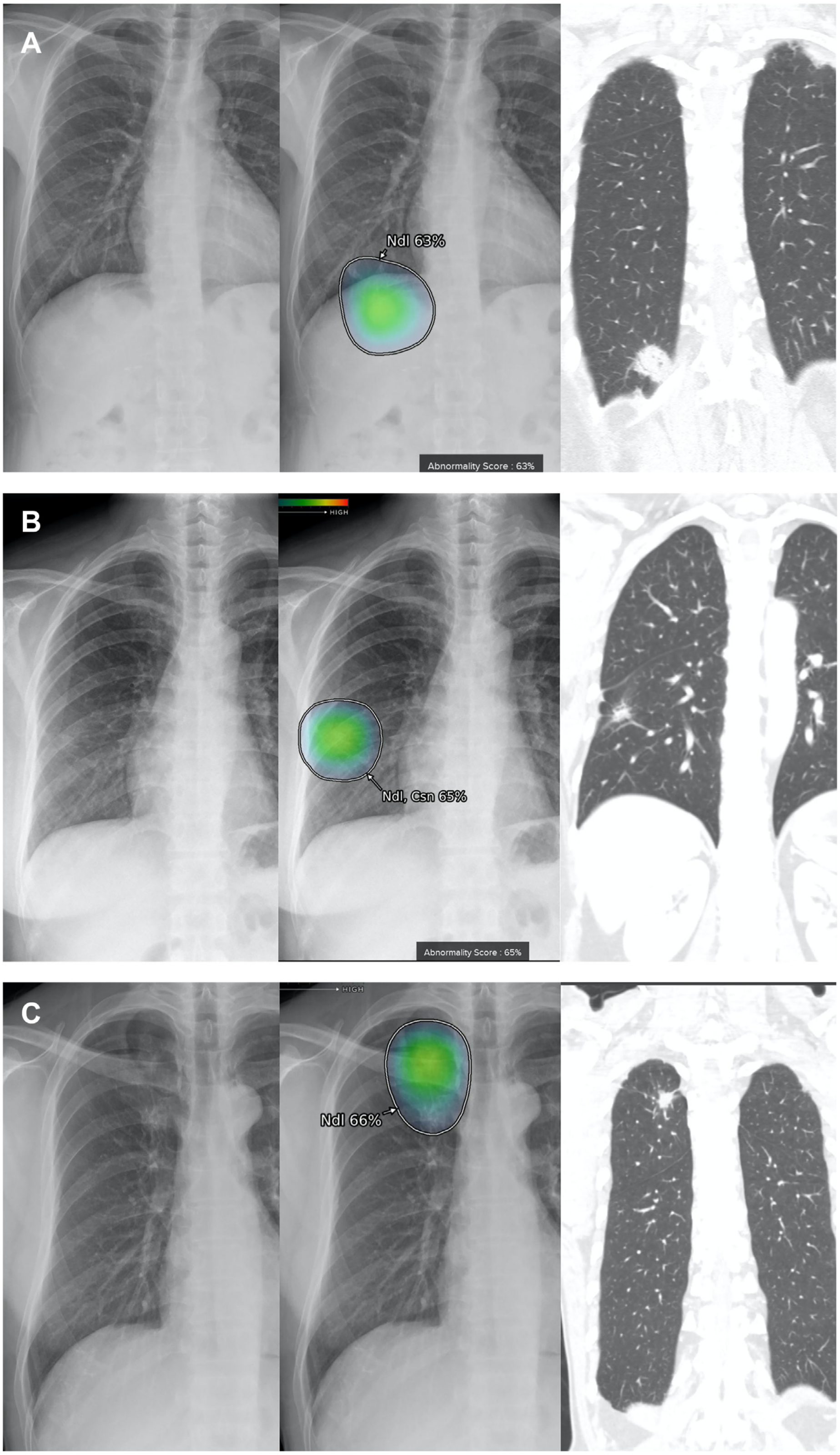

Figure 10 – *Enhanced nodule detection using an artificial intelligence algorithm with correlation to the corresponding reformatted coronal CT scan. A, Images from a 52-y-old woman with a nodule in the blind spot region of the right lower lobe, superimposed on the right hemidiaphragm. B, Images from a 65-y-old woman with a subtle, low-density right lung nodule. C, Images from a 56-y-old man with a subtle right upper lobe nodule. (Courtesy of Dr Jin Mo Goo, Seoul National University Hospital, Seoul, South Korea.)*

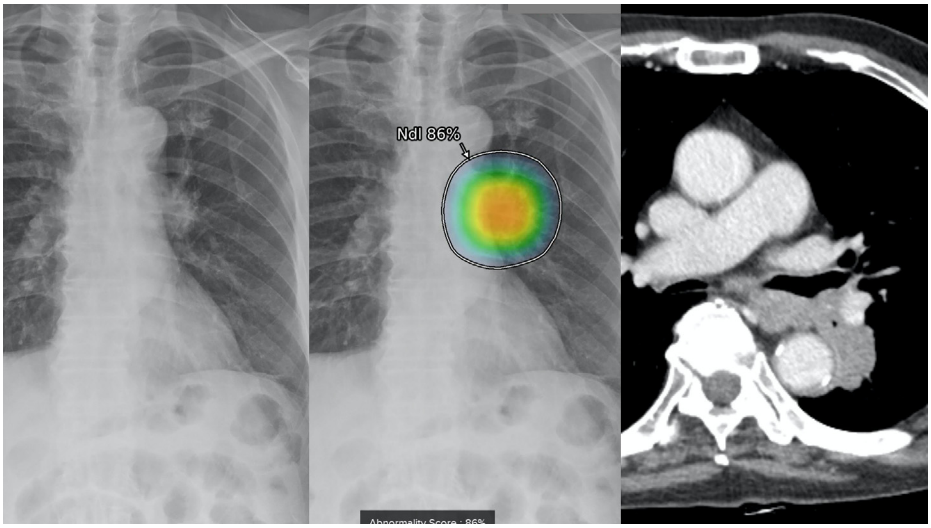

Figure 11 – *Enhanced left hilar mass detection using an artificial intelligence algorithm, with correlation to the corresponding CT image in a 86-y-old man with a left hilar mass resulting from squamous cell carcinoma in the superior segment of the left lower lobe. (Reprinted with permission courtesy of Dr Jin Mo Goo, Seoul National University Hospital, Seoul, South Korea.)*

areas corresponding to possible lung lesions on the frontal view. Although, as noted previously, approximately 85% of the lungs are visible on the posteroanterior view,[8] lung nodules obscured by overlying structures on the posteroanterior radiograph and opacities at the lung bases may be evident on the lateral view only. Any increase in density observed when visually scanning along the thoracic spine in a craniocaudal direction on the lateral radiograph often indicates the presence of an abnormality, including pneumonia or lung cancer (Fig 4). As noted previously, lung blind spots also exist on the lateral view (Fig 1) that should be reviewed carefully.

It is essential to compare the current study with available prior CXR images because this can increase conspicuity of more subtle abnormalities (Fig 8). Any recent chest CT scans also should be reviewed because these can direct attention to CXR findings otherwise missed.

A noncontrast CT scan can be obtained to evaluate an unexplained asymmetry at the apices that was not present on prior studies because this may be indicative

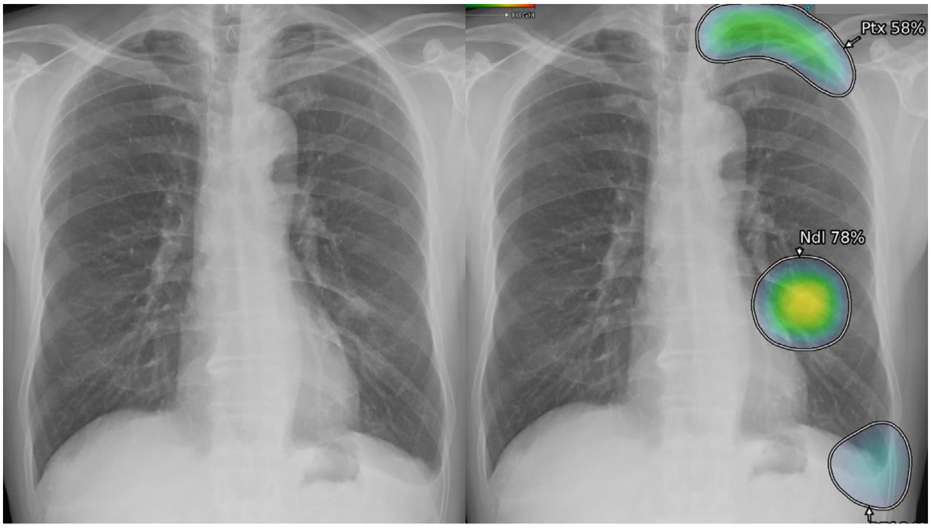

Figure 12 – *Enhanced left apical pneumothorax detection using an artificial intelligence algorithm in a 61-y-old woman after needle biopsy of the small left lung nodule with a small left apical pneumothorax. A small left pleural effusion also is present. (Courtesy of Dr Jin Mo Goo, Seoul National University Hospital, Seoul, South Korea.)*

TABLE 1] Summary of Sources of Errors and General Strategies for Error Reduction in CXR Interpretation

Sources of Error	Error Mitigation Strategies
• Poor lesion conspicuity	• Optimized image quality and display and QA processes
	• Optional use of bone suppression, AI
• Suboptimal ambient conditions (lighting, noise, interruptions)	• Optimal ambient reading conditions
• Incomplete search	• Comprehensive, systematic, consistent visual search
	• Checklist to confirm complete search for commonly missed findings
• Blind spots	• Attention to blind spots
• Satisfaction of search	• Conscious avoidance of satisfaction of search
• Inattentional blindness	• Undivided attention
• Cognitive biases	• Metacognition to avoid biases
	• Debiasing
• Failure to use clinical history, prior imaging studies, lateral CXR images	• Use of clinical history (EMR), prior imaging studies, lateral CXR images
• Suboptimal training, experience	• Experience, knowledge of cardiothoracic anatomy, physiology, and pathology
• Failure to learn from errors	• Educational interventions, just culture

AI = artificial intelligence; CXR = chest radiography; EMR = electronic medical record; QA = quality assuarance.

of a superior sulcus tumor or other carcinoma of the lung. Although lordotic or shallow oblique posteroanterior radiographs may be recommended to evaluate uncertain asymmetries or nodular opacities further, a noncontrast CT scan generally is preferred, particularly if the patient is 60 years of age or older.

Before the emergence of chest CT scans, CXR was the gold standard for chest imaging. The advent of CT scans, including high-resolution CT imaging, clearly has shown CXR's many limitations and blind spots. Missed lung nodules have been illustrated previously. Surprisingly, masses as large as 3 to 4 cm in the hila may escape detection on CXR (Fig 8). Ground-glass pulmonary parenchymal opacities and diffuse lung diseases (both interstitial lung disease and COPD) easily seen on CT imaging may be difficult to detect on CXR images (Fig 13). Entities such as pneumocystis pneumonia, bronchiolitis obliterans, and lymphangioleiomyomatosis may present with CXR images with normal findings. Thus, CXR images must be interpreted and used with these well-known limitations in mind. Noncontrast chest CT imaging may be indicated when a patient's pulmonary signs and symptoms are discordant with the CXR findings.

The Pleura: The pleura then should be inspected from the apices (evaluating for pneumothorax and asymmetric pleural thickening), along the lateral pleura for focal or diffuse pleural thickening or calcification (plaques, fibrotic thickening, and tumor), and continuing to the costophrenic angles (blunting by effusion or pleural thickening). It is important to recognize the presence of a deep sulcus, a finding associated with a supine pneumothorax, as well as flattening of the ipsilateral hemidiaphragm and contralateral mediastinal shift indicative of tension physiologic features. On the lateral view, if available, evaluate the posterior costophrenic angles for small effusions not evident on the posteroanterior view. Complete the inspection of the pleura along the diaphragmatic pleural surfaces.

The Trachea and Central Bronchi: Next, the trachea and main bronchi should be evaluated. Scan vertically from the cervical trachea inferiorly across the thoracic inlet, thoracic trachea, the mainstem bronchi to the hila. Assess for deviations by cervical (thyroid) or mediastinal masses, stenoses (after intubation or tracheostomy), and tumor (Fig 14).

The Hila: Continuing from the main bronchi, the hila should be evaluated. Assess the size, configuration, and density of the hila for mass or lymphadenopathy (Figs 8, 15). Use the lateral view to confirm the findings further. Comparison with prior CXR images is important because a change in the appearance of the hila will increase the conspicuity of hilar lesions. In addition, assess the position of the hila because displacement may

TABLE 2] A Practical Scheme for Interpreting CXR Images and Reducing Error

• The patient name, age, sex, examination date, the presence of a lateral radiograph and prior studies for comparison may be checked quickly.
• Any limitations in image quality should be noted.
• The CXR images may be viewed first without clinical history to eliminate any perceptual or cognitive biases, after which the CXR images can be reviewed in light of the patient's history and to address specific clinical questions.
• Initially, one should look at the CXR images globally. In doing so, the overall lung volumes can be assessed, and any asymmetries or obvious abnormalities in the chest may be evident at a glance.
• Each lung should be visually scanned completely, from apex to below the domes of the diaphragms. In addition, scanning across both lungs horizontally enhances detection of asymmetries, increasing the conspicuity of pulmonary nodules and other parenchymal opacities.
• Attention should be paid to areas of the lung that may be obscured partially by overlying ribs and clavicles.
• A deliberate second visual scan should be made through the known lung blind spots.
• It is important to scrutinize the lungs on the lateral radiograph when acquired, with particular attention to areas corresponding to possible lung lesions on the frontal view. Lung nodules obscured by overlying structures on the posteroanterior radiograph and opacities at the lung bases may be evident on the lateral view only.
• Any increase in density observed when visually scanning along the thoracic spine in a craniocaudal direction on the lateral radiograph often indicates the presence of an abnormality, including pneumonia or lung cancer.
• Also lung blind spots on the lateral view exist that should be reviewed carefully.
• It is essential to compare the current study with available prior CXR images because this can increase conspicuity of more subtle abnormalities. Any recent chest CT scans also should be reviewed because these can direct attention to CXR findings otherwise missed.
• A noncontrast CT scan can be obtained to evaluate an unexplained asymmetry at the apices that was not present on the prior studies because this may be indicative of a superior sulcus tumor or other carcinoma of the lung.
• Next, the pleura should be inspected from the apices (evaluating for pneumothorax, asymmetric pleural thickening), along the lateral pleura for focal or diffuse pleural thickening or calcification (plaques, fibrotic thickening, tumor), and continuing to the costophrenic angles (blunting by effusion or pleural thickening). On the lateral view, if available, evaluate the posterior costophrenic angles for effusions not evident on the posteroanterior view.
• It is important to recognize the presence of a deep sulcus, a finding associated with a supine pneumothorax, as well as flattening of the ipsilateral hemidiaphragm and contralateral mediastinal shift indicative of tension physiologic features.
• Next, the trachea and main bronchi should be evaluated. Scan vertically from the cervical trachea inferiorly across the thoracic inlet, thoracic trachea, the mainstem bronchi to the hila. Assess for deviations by cervical (thyroid) or mediastinal masses, stenoses (after intubation or tracheostomy), and tumor.
• Continuing from the main bronchi, the hila should be assessed. Observe the size, configuration, and density of hila for mass or lymphadenopathy. Use the lateral view to confirm the findings further. Comparison with prior CXR images is important because a change in the appearance of the hila will increase the conspicuity of hilar lesions.
• Evaluate the size and position of the central pulmonary arteries for pulmonary hypertension.
• Next, evaluate the mediastinum scanning superior to inferior, from the thoracic inlet to the diaphragms. Moving one's eyes vertically facilitates evaluation of mediastinal contours and mediastinal lines (ie, interfaces with the air-containing adjacent lung).
• As with the hila, comparison with prior CXR images increases sensitivity to subtle mediastinal contour abnormalities. Note any abnormal mediastinal widening. Assess for mediastinal lymphadenopathy, mediastinal mass, aortic aneurysm or dilatation, and dilated main pulmonary artery. Evaluate the lateral view for anterior, middle, and posterior mediastinal masses.
• Note the presence of any abnormal mediastinal air collections (pneumomediastinum).
• Continuing the evaluation of the lower mediastinum, assess the size and contour of the cardiac silhouette on both the posteroanterior and lateral views. The presence of a globular so-called water-bottle configuration suggesting possible pericardial effusion and pneumopericardium should not be overlooked.
• Continue the visual search below the heart to the diaphragms and upper abdomen. The presence of pneumoperitoneum should not be missed on either the posteroanterior or lateral radiograph.
• It is important then to perform a separate, dedicated inspection of bones, including each rib, thoracic spine (particularly on the lateral view), clavicles, shoulders (scapula, proximal humeri), and sternum on the lateral view.
• The soft tissues, including the breasts, can be searched for abnormal calcifications, possible soft tissue masses, subcutaneous emphysema, and foreign bodies.
• A dedicated search should be performed to evaluate all lines, tubes, and hardware that may be present, identifying any malposition. The search also should be used to detect any radiopaque foreign bodies, particularly if this is of clinical concern.
• An important final step is to integrate all of the observations to formulate overall diagnostic impressions and to gain insight into the patient beyond the image.

CXR = chest radiography.

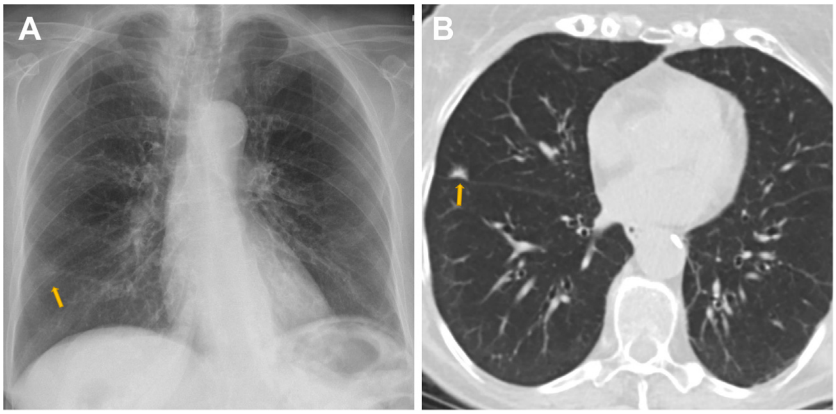

Figure 13 – *Images from an 89-y-old woman with a small, low-density nodule in the right middle lobe. A, Posteroanterior chest radiograph showing a faint asymmetric opacity overlying the anterior aspect of the right fifth rib (arrow). B, Axial noncontrast CT scan demonstrating the corresponding small spiculated nodule in the right middle lobe with traction of the right major fissure (arrow). Lung cancers presenting as small, low-density nodules can be missed on chest radiography. (Reprinted with permission from Gefter et al.[1])*

be a clue to lobar atelectasis (vs scarring). The left hilum is higher than the right in 97% of heathy people and is symmetric in height in only 3% of healthy people. A higher right hilum is indicative of abnormality.[23] Evaluate the size and position of the central pulmonary arteries for pulmonary hypertension.

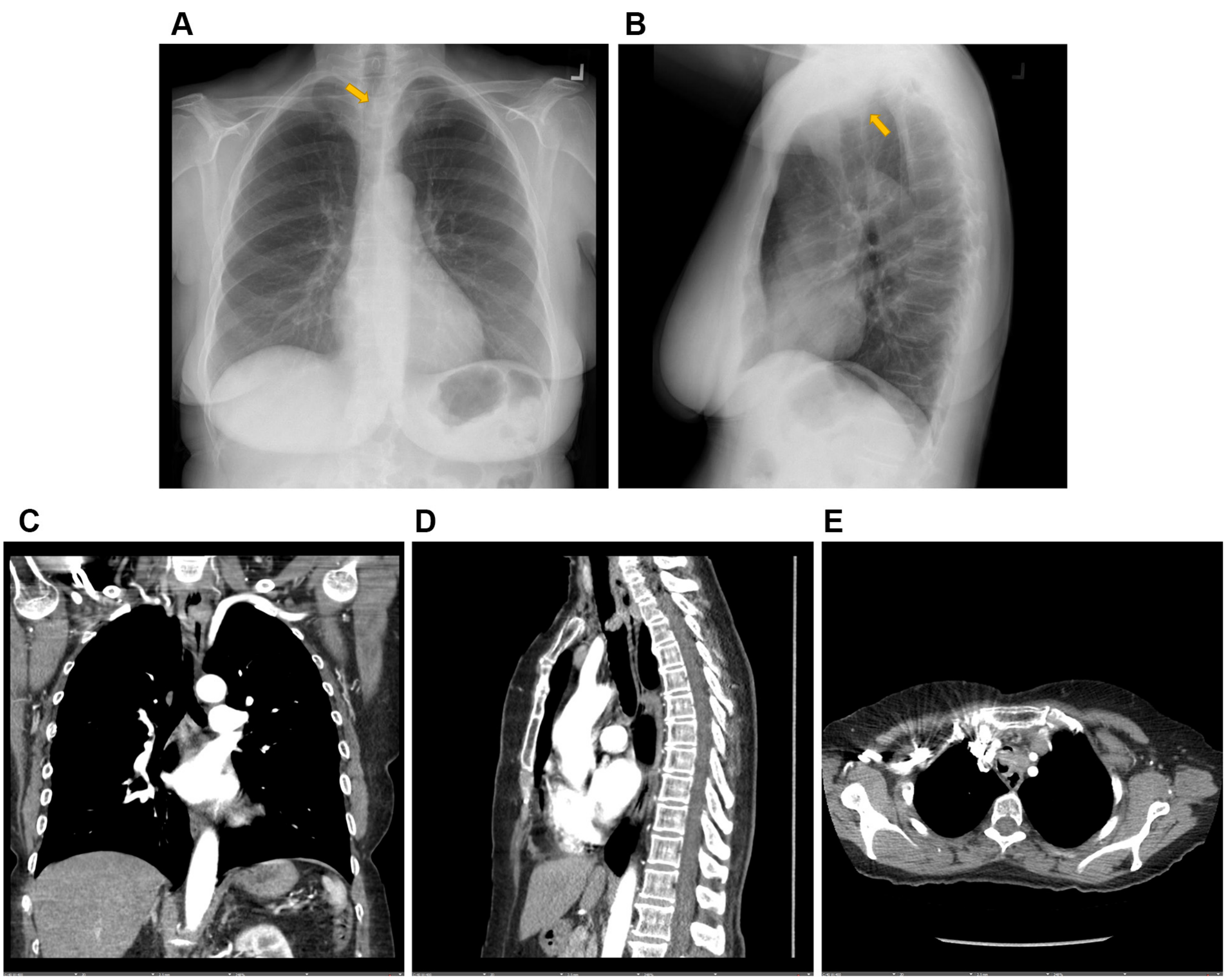

Figure 14 – *Images from a 60-y-old woman with tracheal tumor. A, Posteroanterior chest radiograph showing the increased opacity on the left side of the mid portion of the trachea (arrow). B, Lateral chest radiograph showing that the opacity only vaguely is seen overlying the mid portion of the trachea (arrow). C, D, Coronal reformatted (C) and sagittal reformatted (D) CT scans clearly visualizing the corresponding tumor, which is not detected easily on the posteroanterior and lateral chest radiographs. E, Axial CT scan with contrast enhancement demonstrating the corresponding mass in the trachea with invasion of the surrounding tissue and abutting the left common carotid and left subclavian arteries. The trachea long has been considered a blind spot for radiologists, requiring routine inspection on chest radiography. (Reprinted with permission from Gefter et al.[1])*

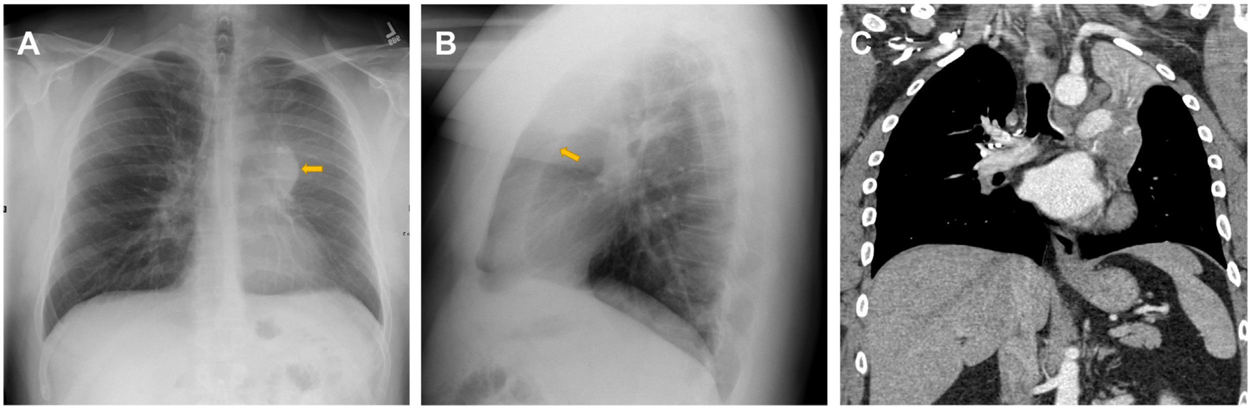

Figure 15 – *Images from a 42-y-old man with left upper lobe atelectasis resulting from a left hilar mass of non-small cell lung cancer. A, Posteroanterior chest radiograph showing that asymmetry is a clue to identifying the abnormality, along with increased size and density of the left hilum (arrow). B, Lateral chest radiograph showing the atelectatic left upper lobe anteriorly (arrow). C, Coronal reformatted CT scan with contrast enhancement demonstrating the left hilar mass with atelectasis. (Reprinted with permission from Gefter et al.[1])*

The Mediastinum: Next, to evaluate the mediastinum scan superior to inferior, from the thoracic inlet to the diaphragms. Moving one's eyes vertically facilitates evaluation of mediastinal contours and mediastinal lines (ie, interfaces with the air-containing adjacent lung). As with the hila, comparison with prior CXR images increases sensitivity to subtle contour abnormalities. Note any abnormal mediastinal widening. Assess for mediastinal lymphadenopathy, mediastinal mass, aortic aneurysm or dilatation (Fig 16), and dilated main pulmonary artery. Evaluate the lateral view for anterior, middle, and posterior mediastinal masses. Note the presence of any abnormal mediastinal air collections (pneumomediastinum).

The Heart: Continuing the evaluation of the lower mediastinum, assess the size and contour of the cardiac silhouette on both the posteroanterior and lateral views. The presence of a globular so-called water-bottle configuration suggesting possible pericardial effusion and pneumopericardium should not be overlooked.

The Diaphragms and Upper Abdomen: Continue the visual search below the heart to the diaphragm and upper abdomen. The presence of pneumoperitoneum should not be missed on either the posteroanterior or lateral radiograph (Fig 17).

The Bones: It is important then to perform a separate, dedicated inspection of bones, including each rib, thoracic spine (particularly on the lateral view), clavicles, shoulders (scapula and proximal humeri), and sternum on the lateral view.

The Soft Tissues: The soft tissues, including the breasts, can be searched for abnormal calcifications, possible soft tissue masses, subcutaneous emphysema, and foreign bodies.

Lines, Tubes, Hardware, and Radiopaque Foreign Bodies: A dedicated search should be performed specifically to evaluate all lines, tubes, and hardware that may be present, identifying any malposition (Fig 18). The search also should be used to detect any radiopaque foreign bodies, particularly if this is of clinical concern.

Integration of Findings: An important final step is to integrate all of the observations to formulate overall diagnostic impressions and to gain insight into the patient beyond the image.

The Use of a Checklist

Author and surgeon Atul Gawande, in his influential book *The Checklist Manifesto: How to Get Things Right*, emphasizes that even experts make avoidable errors.[24] He demonstrates that checklists can be an effective, low-tech approach to reducing such errors. Initially used successfully in aviation, checklists have been adopted in clinical settings. Their use in operating rooms has reduced surgical fatalities by more than one-third.[24] Checklists have been applied to CXR interpretation.[25,26,27] They have the potential to ensure a consistent, systematic, and comprehensive search of CXR images for commonly missed findings.

For radiologists, structured reports with standardized templates serve as checklists during image

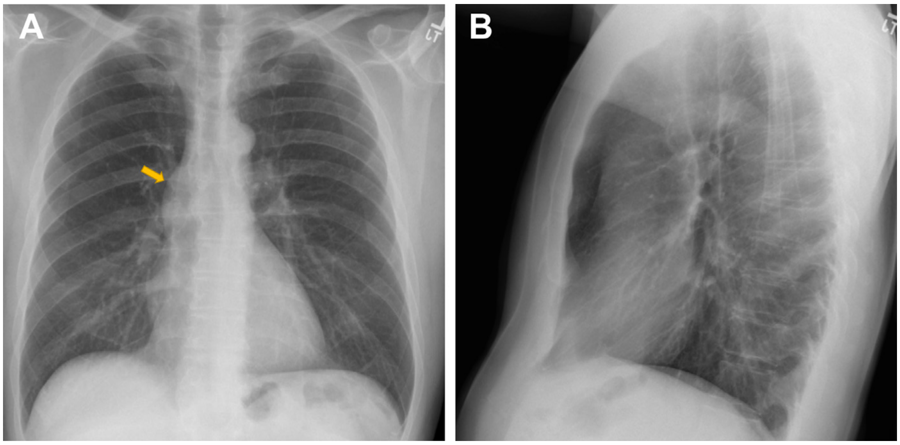

Figure 16 – *A, B, Frontal (A) and lateral (B) chest radiographs from a 54-y-old male renal donor with markedly dilated ascending aorta (arrow). (Reprinted with permission from Gefter et al.[1])*

interpretation.[13] They potentially can include prompts to look for specific findings that are overlooked frequently.[7] However, to be effective, such checklists must not be time-consuming nor disruptive to the usual reading strategy.[25,26] For all other clinicians interpreting CXR images, a checklist may serve as a useful guide. Limited studies have demonstrated improved detection of CXR abnormalities among less experienced readers.[26]

Table 3 lists commonly missed findings, ordered by anatomic compartments in accordance with the visual search scheme described previously. Major methods to minimize the risk of overlooking commonly missed, actionable findings are listed. As shown in Table 3, this can form the basis for a checklist. Although serving as a sample checklist, it is intended to be flexible and modified as necessary to achieve the optimal balance between effectiveness and efficiency. Other items that could be included in such a checklist are: confirmation of the correct patient, lateral radiograph reviewed if acquired, comparison made with prior examinations if available, clinical history reviewed, and supplemental computer-aided images (AI, bone suppression) reviewed if obtained.

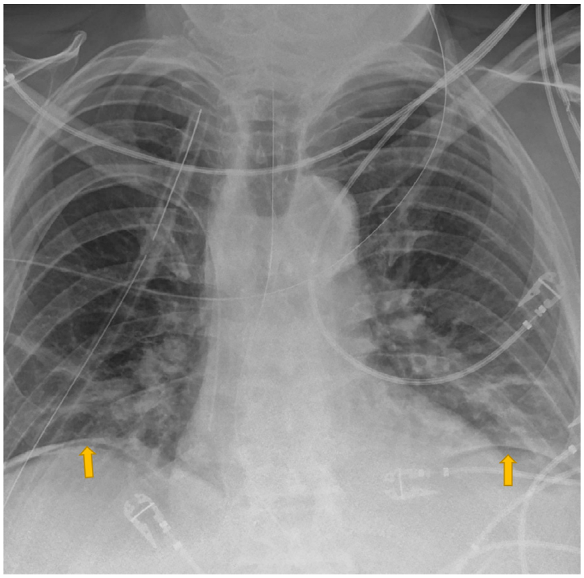

Figure 17 – *Chest radiograph from a 58-y-old man with pneumoperitoneum (arrows) who underwent esophagectomy with gastric pull-through. (Reprinted with permission from Gefter et al.[1])*

Continued CXR Interpretive Performance Improvement: Errors as Educational Opportunities

Most important for the development of expert perceptual and interpretive skills are experience and knowledge. Extensive experience is required to develop highly efficient and effective visual search and the detection and recognition of an abnormality. Knowledge of thoracic imaging, anatomic features, cardiopulmonary physiologic features, and pathologic features is needed for both identification of an abnormality as well as skilled decision-making regarding its clinical significance. Unfortunately, in this age of CT scan imaging, less emphasis is placed on learning anatomic features on CXR, such as mediastinal lines, hilar or bronchial anatomic features, and anatomic features on the lateral radiograph, all of which can indicate the presence of abnormalities.

Errors provide opportunities for education as well as process improvement.[12] This requires a just culture promoting safe, nonpunitive, and blameless recognition and reporting of errors.[13] Educational interventions using errors as learning opportunities include: (1) missed case, discrepancy, and multidisciplinary conferences; (2) peer-review processes, with either

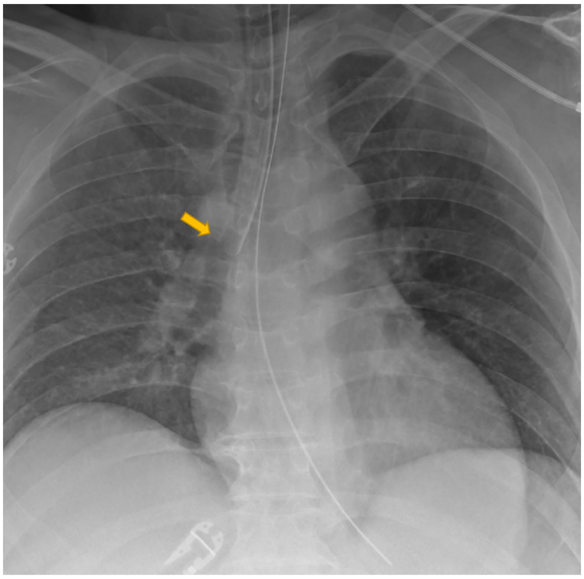

Figure 18 – *Chest radiograph from a 42-y-old man with malpositioned endotracheal tube in the right main bronchus (arrow). (Reprinted with permission from Gefter et al.[1])*

random case review or nonrandom cases with errors; and (3) conferences to discuss error mitigation strategies.[7] We tend to remember and learn most from our mistakes.

Summary

CXR, the most frequently performed imaging examination, is vulnerable to interpretation errors resulting from commonly missed findings.[1] Clinicians interpreting these studies should develop strategies to reduce such errors. These approaches, summarized in Table 1, include a consistent, systematic, and comprehensive visual search pattern, with attention to known blind spots. To achieve this, a practical CXR interpretation scheme is presented. In addition, a checklist to be certain that commonly missed findings have been evaluated can be integrated into this interpretation scheme, as shown in Table 3. Technical advances that can enhance the visibility and detection of abnormal CXR findings include bone suppression and

TABLE 3] Commonly Missed Findings and Major Approaches to Avoiding These Errors

Sequential Search	Commonly Missed Findings	Avoiding Errors	Reviewed
Lungs	• Nodule, mass ∘ Superior sulcus tumor • Pneumonia • Lobar atelectasis	• Second look at all blind spots • Lateral CXR image (if available) • Attention to asymmetric opacity, hilar displacement	□
Pleura	• Subtle pneumothorax ∘ Supine ∘ Tension • Pleural effusion	• Detection of thin visceral pleural line • Deep sulcus sign • Depressed diaphragm, mediastinal shift • Posterior costophrenic angle blunting lateral	□
Trachea and central bronchi	• Stenosis ∘ Primary tumor, scarring • Displacement ∘ Extrinsic mass (thyroid, other)	• Search cervical trachea to mainstem bronchi	□
Hila	• Mass, lymphadenopathy • Enlarged pulmonary arteries (pulmonary hypertension)	• Size, configuration, density, position	□
Mediastinum/Heart	• Mass, lymphadenopathy • Aortic aneurysm, dilatation • Widening (bleed) • Pneumomediastinum, pneumopericardium	• Mediastinal contours • Mediastinal lines • Cardiac contours • Abnormal air collections	□
Upper abdomen	• Pneumoperitoneum	• Continue visual search below diaphragms	□
Bones	• Fractures • Metastases	• Lateral: spinal compression fractures • Ribs, clavicles, shoulders, proximal humeri, spine, sternum	□
Hardware	• Malpositioned lines, tubes	• Focused search	□
Foreign bodies	• Abnormal, retained, radiopaque foreign bodies	• Review clinical history • Dedicated search	□

Errors are listed by anatomic compartment in the sequence of visual search. This forms the basis for developing a checklist, as denoted in the right-hand column. CXR = chest radiography.

AI. The latter is emerging rapidly and is highly promising. Because we tend to remember and learn most from our mistakes, errors can provide important educational and quality-improvement opportunities, if addressed in a just, nonpunitive culture.

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Dedication: This article is dedicated to the memory of Wallace T. Miller, Sr., MD. "Wally Sr." was a master chest radiologist, clinician, teacher, and role model. He showed us that the chest radiograph is not simply an image, but a portal through which one can gain deep clinical insights into a patient.

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