American College of Radiology
ACR Appropriateness Criteria®

Incidentally Detected Indeterminate Pulmonary Nodule

Variant: 1 Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on chest radiograph. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
CT chest without IV contrast	Usually Appropriate	☢☢☢
Radiography chest	May Be Appropriate	☢
Image-guided transthoracic needle biopsy	Usually Not Appropriate	Varies
MRI chest without and with IV contrast	Usually Not Appropriate	O
MRI chest without IV contrast	Usually Not Appropriate	O
CT chest with IV contrast	Usually Not Appropriate	☢☢☢
CT chest without and with IV contrast	Usually Not Appropriate	☢☢☢
FDG-PET/MRI whole body	Usually Not Appropriate	☢☢☢
FDG-PET/CT whole body	Usually Not Appropriate	☢☢☢☢

Variant: 2 Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule less than 6 mm on chest CT. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
CT chest without IV contrast	May Be Appropriate	☢☢☢
Radiography chest	Usually Not Appropriate	☢
Image-guided transthoracic needle biopsy	Usually Not Appropriate	Varies
MRI chest without and with IV contrast	Usually Not Appropriate	O
MRI chest without IV contrast	Usually Not Appropriate	O
CT chest with IV contrast	Usually Not Appropriate	☢☢☢
CT chest without and with IV contrast	Usually Not Appropriate	☢☢☢
FDG-PET/MRI whole body	Usually Not Appropriate	☢☢☢
FDG-PET/CT whole body	Usually Not Appropriate	☢☢☢☢

Variant: 3 Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule equal to or greater than 6 mm on chest CT. Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
CT chest without IV contrast	Usually Appropriate	☢☢☢
FDG-PET/CT whole body	Usually Appropriate	☢☢☢☢
Image-guided transthoracic needle biopsy	May Be Appropriate	Varies
Radiography chest	Usually Not Appropriate	☢
MRI chest without and with IV contrast	Usually Not Appropriate	O
MRI chest without IV contrast	Usually Not Appropriate	O
CT chest with IV contrast	Usually Not Appropriate	☢☢☢
CT chest without and with IV contrast	Usually Not Appropriate	☢☢☢
FDG-PET/MRI whole body	Usually Not Appropriate	☢☢☢

Variant: 4 Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on incomplete thoracic CT (eg, CT abdomen, neck, spine, etc). Next imaging study.

Procedure	Appropriateness Category	Relative Radiation Level
CT chest without IV contrast	Usually Appropriate	☢☢☢
Radiography chest	Usually Not Appropriate	☢
Image-guided transthoracic needle biopsy	Usually Not Appropriate	Varies
MRI chest without and with IV contrast	Usually Not Appropriate	O
MRI chest without IV contrast	Usually Not Appropriate	O
CT chest with IV contrast	Usually Not Appropriate	☢☢☢
CT chest without and with IV contrast	Usually Not Appropriate	☢☢☢
FDG-PET/CT whole body	Usually Not Appropriate	☢☢☢☢

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Summary of Literature Review

Introduction/Background

A pulmonary nodule is defined as a well or poorly defined rounded opacity measuring <3 cm in diameter [1-5]. Nodules are classified as solid, part-solid, and ground-glass on CT, based on their attenuation, allowing for a more accurate assessment of malignancy risk. Ground-glass nodules are areas of increased attenuation through which underlying structures such as vessels remain visible [3]. Incidental pulmonary nodules are common, with reported frequencies ranging from 5.6% to 51% on CT and 0.1% to 7% on chest radiographs [5-7]. While it is estimated that 70% to 97% of incidental pulmonary nodules are benign [8], most are indeterminate for malignancy when first encountered making their management challenging.

Guidelines from the Fleischner Society and American College of Chest Physicians (ACCP) were developed to help manage incidental pulmonary nodules based on a nodule's potential for clinically significant disease [2,9]. The most updated guidelines recommend follow-up tests in patients with an estimated lung cancer risk of ≥1%, allow flexibility to accommodate a patient's risk factors and preferences in management, and aim to reduce the number of follow-up examinations [9]. The recommendations in this document apply to nodules without associated abnormalities such as lymphadenopathy, pleural effusion, or atelectasis. The recommendations also apply to the same patient population as the Fleischner Society guidelines, including individuals who are ≥35 years of age, immunocompetent, and without a diagnosis of cancer at risk for metastasis [9]. Incidental pulmonary nodules found in patients <35 years of age are rarely malignant and more

likely to represent infection; therefore, management in these patients should be made on a case-by-case basis [9,10]. The variants in this document do not apply to nodules found during lung cancer screening, for which Lung-RADS® guidelines were developed [11,12]. Finally, patients with unexplained fever or unexplained symptoms should also be excluded, in line with the ACR recommendations for management of incidental findings on thoracic CT [12].

Special Imaging Considerations

Bones limit the ability to detect pulmonary nodules on chest radiographs. Studies show that 35% to 95% of missed lung cancers were obscured or partially obscured by bones [13-16]. Methods to attenuate bones on radiographs have been developed to enhance lung nodule detection, including dual-energy subtraction radiography and bone suppression imaging software. These methods improve a radiologist's detection of lung nodules in small series [13,17]. However, implementation of these techniques is not always feasible, and there is not sufficient literature to support their widespread use in the initial evaluation of incidental pulmonary nodules.

Additional methods that can enhance the detection and characterization of lung nodules include computer-aided detection systems [18-20], pulmonary vessel subtraction [21,22], deep convolutional neural networks [23], and other artificial intelligence algorithms [24]. While some practices use these methods, a detailed discussion falls outside of the scope of this document.

Discussion of Procedures by Variant

Variant 1: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on chest radiograph. Next imaging study.

Variant 1: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on chest radiograph. Next imaging study.
A. CT Chest Without IV Contrast

For individuals with an indeterminate pulmonary nodule detected on chest radiograph, ACCP guidelines recommend reviewing prior studies to determine stability. If the nodule has been stable for at least 2 years, no further workup is advised. If stability cannot be determined, guidelines recommend performing a chest CT to better characterize the nodule [2].

CT is widely recognized as the modality of choice to evaluate pulmonary nodules. Thin-section CT is estimated to be 10 to 20 times more sensitive than standard radiography and allows better nodule characterization [3,25,26]. Nodule detection and characterization on CT is directly related to image quality and therefore technique, with reported detection sensitivities ranging from 30% to 97% [20]. Factors associated with increased sensitivity include thinner CT sections, nodule location and larger size, and nodule attenuation [20]. Guidelines for nodule management recommend routine use of contiguous thin sections (≤1.5 mm) and reconstructed multiplanar images to ensure adequate characterization, particularly for nodules with a ground-glass attenuation component. In addition, low-dose technique is recommended for CTs performed to follow lung nodules [9]. Intravenous (IV) contrast is not required to identify or initially characterize pulmonary nodules in clinical practice [27], which is also supported in lung cancer screening in which IV contrast is not used.

There are advantages of using CT as the first step in the characterization of pulmonary nodules

detected on radiographs. Overlapping structures that might be causing pseudonodules are removed. Certain nodule characteristics suggestive of benign etiology are better appreciated by CT and can avoid additional workup. For example, diffuse, central, laminated, or popcorn calcifications patterns are predictors of benign etiology (odds ratio [OR] = 0.07-0.20) [28]. Macroscopic fat is another indicator of benign etiology typical of hamartomas, which cannot be appreciated on radiographs. The mean attenuation value of indeterminate benign and malignant nodules on unenhanced CT is not significantly different and therefore not useful in their differentiation. However, multiple imaging features that increase the risk of malignancy are best characterized on CT, including nodule size, morphology, location, multiplicity, or the presence of emphysema or fibrosis. Unsuspected associated processes such as lymphadenopathy can sometimes be detected on CT, and CT can help with planning next steps such as biopsy when indicated [2].

Variant 1: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on chest radiograph. Next imaging study.
B. CT Chest Without and With IV Contrast

There is no relevant literature to support the use of dynamic contrast-enhanced CT in the initial evaluation of incidentally detected indeterminate pulmonary nodules on chest radiographs. IV contrast is not required to identify or initially characterize pulmonary nodules on CT [27].

Variant 1: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on chest radiograph. Next imaging study.
C. CT Chest With IV Contrast

There is no relevant literature to support the use of contrast-enhanced CT in the initial evaluation of incidentally detected indeterminate pulmonary nodules on chest radiographs. IV contrast is not required to identify or initially characterize pulmonary nodules on CT [27]. Cancer staging, an incidental mass workup, and nodules with associated lymphadenopathy fall outside of the scope of this document.

Variant 1: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on chest radiograph. Next imaging study.
D. FDG-PET/CT Whole Body

There is no relevant literature to support the use of fluorine-18-2-fluoro-2-deoxy-D-glucose (FDG)-PET/CT in the initial evaluation of incidentally detected indeterminate pulmonary nodules on chest radiographs.

Variant 1: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on chest radiograph. Next imaging study.
E. FDG-PET/MRI Whole Body

There is no relevant literature to support the use of FDG-PET/MRI in the evaluation of incidentally detected indeterminate pulmonary nodules.

Variant 1: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on chest radiograph. Next imaging study.
F. Image-Guided Transthoracic Needle Biopsy

There is no relevant literature to support the use of image-guided transthoracic needle biopsy (TNB) in the initial evaluation of incidentally detected indeterminate pulmonary nodules on chest radiographs.

Variant 1: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on chest radiograph. Next imaging study.

G. MRI Chest Without IV Contrast

There is no relevant literature to support the use of MRI chest in the initial evaluation of incidentally detected indeterminate pulmonary nodules on chest radiographs.

Variant 1: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on chest radiograph. Next imaging study.
H. MRI Chest Without and With IV Contrast

There is no relevant literature to support the use of dynamic MRI chest in the initial evaluation of incidentally detected indeterminate pulmonary nodules on chest radiographs.

Variant 1: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on chest radiograph. Next imaging study.
I. Radiography Chest

About 20% of suspected nodules on chest radiographs prove to be pseudonodules. These are generally caused by rib fractures, skin lesions, anatomic variants, or overlapping structures [25]. Repeat radiographs with nipple markers, chest fluoroscopy, oblique chest views, and dual-energy subtraction radiography have been described to help distinguish between a pulmonary nodule and a pseudonodule to avoid additional or invasive workup [25]. There is insufficient literature to support their widespread use, and validation studies are needed to measure the effectiveness of newer techniques like dual-energy subtraction. Despite the lack of sufficient literature supporting these methods, the panel consensus was that a repeat chest radiograph is a common practice and may be a useful next step when a pseudonodule is suspected on a radiograph.

When encountering indeterminate solid nodules on chest radiograph, ACCP guidelines recommend thin-section chest CT as the next step unless prior imaging is available to prove stability over 2 years (grade 1C recommendation) [2]. The purpose is to better characterize the nodule and asses its malignant potential. To our knowledge, there is no relevant literature describing effective ways to discriminate between benign and malignant nodules on radiographs [2].

Variant 2: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule less than 6 mm on chest CT. Next imaging study.

Variant 2: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule less than 6 mm on chest CT. Next imaging study.
A. CT Chest Without IV Contrast

For incidental indeterminate pulmonary nodules measuring <6 mm on chest CT, Fleischner Society guidelines do not recommend routine follow-up given the likelihood of malignancy is <1%. There are exceptions for nodules with suspicious imaging features that increase the malignancy risk to the 1% to 5% range. These features are described in Appendix 1. In those cases, a follow-up chest CT may be appropriate at different time intervals, which are based on nodule attenuation, after considering a patient's preferences and comorbidities [9].

CT is widely recognized as the modality of choice to evaluate pulmonary nodules. Nodule detection and characterization on CT is directly related to image quality and therefore technique, with reported detection sensitivities ranging from 30% to 97% [20]. Factors associated with increased sensitivity include thinner CT sections, nodule location and larger size, and nodule attenuation [20]. Guidelines for nodule management recommend routine use of contiguous thin

sections (≤1.5 mm) and reconstructed multiplanar images to ensure adequate characterization, particularly for nodules with a ground-glass attenuation component. If the initial CT was performed with thick sections, obtaining the follow-up CT with ≤1.5 mm sections is encouraged. Low-dose technique is recommended for CTs performed to follow lung nodules [9]. Standardization of acquisition and reconstruction CT protocols will ideally result in more accurate comparisons by reducing the risk of errors measuring nodule size, attenuation, and volume [9,27]. IV contrast is not required to identify, characterize, or determine stability of pulmonary nodules in clinical practice [27], which is also supported in lung cancer screening in which IV contrast is not used.

The mean attenuation value of indeterminate benign and malignant nodules on unenhanced CT is not significantly different and therefore not useful in their differentiation. However, multiple imaging features that increase the risk of malignancy are best characterized on CT including nodule size, morphology, location, multiplicity, or the presence of emphysema or fibrosis. Even though nodules **<**6 mm have a malignancy risk <1%, an optional follow-up CT can be recommended if some of these features are present (see Appendix 1).

Variant 2: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule less than 6 mm on chest CT. Next imaging study.
B. CT Chest Without and With IV Contrast

There is no relevant literature to support the use of dynamic contrast-enhanced CT in the evaluation of incidentally detected indeterminate pulmonary nodules measuring <6 mm on chest CT. The role of dynamic contrast-enhanced CT in the evaluation of pulmonary nodules has been proposed to differentiate benign from malignant nodules classified as indeterminate by CT. The majority of nodules included on these studies are ≥10 mm [29-31].

Variant 2: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule less than 6 mm on chest CT. Next imaging study.
C. CT Chest With IV Contrast

There is no relevant literature to support the use of contrast-enhanced CT in the evaluation of incidentally detected indeterminate pulmonary nodules measuring <6 mm on chest CT. IV contrast is not required to identify or determine stability of pulmonary nodules [27].

Variant 2: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule less than 6 mm on chest CT. Next imaging study.
D. FDG-PET/CT Whole Body

There is no relevant literature to support the use of FDG-PET/CT in the evaluation of incidentally detected indeterminate pulmonary nodules measuring <6 mm on chest CT. The role of FDG-PET/CT in the differentiation of benign from malignant nodules has been extensively studied and relies on measuring glucose metabolism, which is typically elevated on malignant lesions. Reported sensitivities and specificities range from 88% to 96% and 77% to 88%, respectively [1,5,32]. FDG-PET/CT limited spatial resolution results in suboptimal evaluation of small pulmonary nodules; therefore, guidelines only recommend FDG-PET/CT for the management of incidental solid pulmonary nodules >0.8 cm as one of the potential next steps [2,9]. To our knowledge, FDG-PET/CT has no clinical role in the initial evaluation of incidental pulmonary nodules measuring ≤8 mm.

Variant 2: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule less than 6 mm on chest CT. Next imaging study.
E. FDG-PET/MRI Whole Body

There is no relevant literature to support the use of FDG-PET/MRI in the evaluation of incidentally detected indeterminate pulmonary nodules.

Variant 2: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule less than 6 mm on chest CT. Next imaging study.
F. Image-Guided Transthoracic Needle Biopsy

There is no relevant literature to support the use of image-guided TNB in the evaluation of incidentally detected indeterminate pulmonary nodules measuring <6 mm on chest CT. Biopsy is only suggested as one of the potential next steps in the evaluation of indeterminate pulmonary nodules ≥0.8 cm to help determine the likelihood of malignancy [9].

Variant 2: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule less than 6 mm on chest CT. Next imaging study.
G. MRI Chest Without IV Contrast

There is no relevant literature to support the use of MRI chest in the evaluation of incidentally detected indeterminate pulmonary nodules measuring <6 mm on chest CT.

Variant 2: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule less than 6 mm on chest CT. Next imaging study.
H. MRI Chest Without and With IV Contrast

There is no relevant literature to support the use of dynamic MRI chest in the evaluation of incidentally detected indeterminate pulmonary nodules measuring <6 mm on chest CT.

Variant 2: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule less than 6 mm on chest CT. Next imaging study.
I. Radiography Chest

There is no relevant literature to support the use of chest radiographs in the evaluation or follow up of incidentally detected indeterminate pulmonary nodules on chest CT. Radiograph's sensitivity for detecting nodules is low, with a significant number of nodules missed [5]. Most nodules <1 cm are not visible in chest radiographs [9].

Variant 3: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule equal to or greater than 6 mm on chest CT. Next imaging study.

Variant 3: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule equal to or greater than 6 mm on chest CT. Next imaging study.
A. CT Chest Without IV Contrast

recommend a follow-up CT at different time intervals, PET/CT, tissue sampling, or a combination depending on nodule size, attenuation, morphology, comorbidities, and other factors. Please refer to Appendix 2 for details [9]. For indeterminate nodules >6 mm, ACCP guidelines recommend follow-up CT at different time intervals, PET/CT, biopsy, or standard staging evaluation depending on nodule size, attenuation, risk factors for lung cancer, surgical risk, and clinical probability of cancer [2]. Guidelines emphasize clinicians should discuss risks and benefits of management strategies with patients and incorporate their preferences.

CT is widely recognized as the modality of choice to evaluate pulmonary nodules. Nodule detection and characterization on CT is directly related to image quality and therefore technique,

with reported detection sensitivities ranging from 30% to 97% [20]. Factors associated with increased sensitivity include thinner CT sections, nodule location and larger size, and nodule attenuation [20]. Guidelines for nodule management recommend routine use of contiguous thin sections (≤1.5 mm) and reconstructed multiplanar images to ensure adequate nodule characterization, particularly for nodules with a ground-glass attenuation component. If the initial CT was performed with thick sections, obtaining the follow-up CT with ≤1.5 mm sections is encouraged. Low-dose technique is recommended for CTs performed to follow lung nodules [9]. Standardization of acquisition and reconstruction CT protocols will ideally result in more accurate comparisons by reducing the risk of errors measuring nodule size, attenuation, and volume [9,27]. IV contrast is not required to identify, characterize, or determine stability of pulmonary nodules in clinical practice [27], which is also supported in lung cancer screening in which IV contrast is not used.

Certain nodule characteristics suggestive of benign etiology are better appreciated by CT and can avoid additional workup. For example, diffuse, central, laminated, or popcorn calcifications patterns are predictors of benign etiology ([OR] = 0.07-0.20) [28]. Macroscopic fat is another indicator of benign etiology typical of hamartomas, which cannot be appreciated on radiographs. The mean attenuation value of indeterminate benign and malignant nodules on unenhanced CT is not significantly different and therefore not useful in their differentiation. However, multiple imaging features that increase the risk of malignancy are best appreciated on CT, including nodule size, morphology, location, multiplicity, and the presence of emphysema or fibrosis. For nodules ≥6 mm, some of these features can help select the timing of follow-up studies or preferred next step for suspicious nodules. Unsuspected associated processes such as lymphadenopathy can sometimes be detected on CT, and CT can help with planning next steps such as biopsy when indicated [2].

Female sex is included in the Brock University prediction model as a predictor of lung cancer [28]. Our literature search included a study by Chilet-Rosell et al [33] evaluating management differences between 545 men and 347 women from two institutions following the detection of incidental pulmonary nodules over 5 years. If the nodule was detected by CT, men were more likely to have immediate testing than women ($P < .001$), and women were followed-up more frequently than men ($P < .001$). In the multivariate analysis adjusted by age, smoking status, chronic obstructive pulmonary disease, and nodule characteristics, women were still more likely than men to be followed-up ($P = .002$). The median time between nodule detection and those diagnosed with lung cancer was 1.5 months for men and 4.2 months for women (no statistical difference). Authors raise the question that management variability could be related to a false belief that lung cancer is considered a disease of men. This was a small study, and further research exploring management differences are warranted to better understand the impact of sex in the management of lung nodules.

Variant 3: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule equal to or greater than 6 mm on chest CT. Next imaging study.

B. CT Chest Without and With IV Contrast

There is not enough high-quality evidence to support the use of chest CT without and with IV contrast in the initial evaluation of patients presenting with incidentally detected indeterminate pulmonary nodules ≥6 mm on chest CT. For incidental indeterminate pulmonary nodules measuring ≥6 mm on chest CT, Fleischner Society guidelines recommend a follow-up CT at

different time intervals, PET/CT, tissue sampling, or a combination depending on nodule size and attenuation, morphology, comorbidities, and other factors. Please refer to Appendix 2 for details [9].

Vascularity differences between benign and malignant nodules have been described showing that malignant nodules are more vascular [30]. Nodule enhancement, which reflects vascularity, can be quantified with dynamic contrast-enhanced CT. This technique is highly sensitive in detecting malignant nodules but is nonspecific, mainly because of active inflammatory and infectious nodules also showing high vascularity [2,28]. Different enhancement cut-off values have been proposed to help with this problem. Lower cut-offs generally come with higher sensitivity but decreased specificity. Perfusion values are also influenced by technique, highlighting the need to be cautious when generalizing study results [34].

A multicenter prospective study evaluated the enhancement of 356 indeterminate solid nodules ≥5 mm at CT. Nodules were imaged once without IV contrast and at one-minute intervals after contrast injection for 4 minutes. Absence of significant nodule enhancement was a strong predictor of benignity (sensitivity 98%, specificity 58%, accuracy 77%, negative predictive value [NPV] 96%, positive predictive value [PPV] 68%). The enhancement of the four false-negative nodules was very close to the cut-off value for significance. When lowering the threshold, sensitivity increased to 100% and specificity decreased to 50.3% (NPV 100%, PPV 65%). Authors recommended using this technique in nodules ≤2 cm because of their higher likelihood of being benign, potential difficulty obtaining tissue samples, and less chance of smaller nodules showing substantial necrosis. A detailed breakdown of nodule size is not reported, but the mean size ± SD was 16.9 ± 5.5 for malignant nodules and 13.9 ± 5.1 for benign nodules [31]. In a single-center study of 131 patients, a different cut-off value to differentiate benign and malignant nodules showed sensitivity, specificity, accuracy, NPV, and PPV of 99%, 54%, 78%, 97%, and 71%, respectively [31]. Nearly all nodules included in the study (129/131) were ≥10 mm. Other authors investigated the added value of wash-in and wash-out characteristics of 107 solid indeterminate nodules ≥5.6 mm; 90% of the nodules in this study (96/107) were ≥10 mm. For their enhancement parameters, authors reported sensitivities of 94% to 100%, a specificity of 48% to 90%, and an accuracy of 72% to 92%. Authors also added that the clinical value of dynamic contrast-enhanced CT for the differentiation of malignant from benign nodules may be in the evaluation of small incidental pulmonary nodules in which it is difficult to perform biopsy. Limitations of this study included not having pathologic diagnosis for all benign nodules, nonstandardization of contrast technique, and selection bias. Radiation dose was also discussed, suggesting their technique might not be appropriate for women with low pretest probability of malignancy [29]. Several other series have reported low specificity values [2,32].

Although enhancement patterns of solid nodules have been widely studied, this is not the case for part-solid nodules. Cohen et al [35] retrospectively studied the differences in semiautomated attenuation measurements on unenhanced and enhanced CTs of 53 adenocarcinomas presenting as part-solid nodules. The study showed that most parameters were significantly increased on enhanced CT, including longest transverse diameter of the whole nodule, the solid component, nodule volume and mass, solid component volume and mass, and nodule attenuation. The only parameter that was not significantly elevated was the solid component attenuation, highlighting that caution must be taken when comparing part-solid nodules obtained on studies with and without IV contrast.

Dynamic contrast-enhanced CT was a promising technique to differentiate benign from malignant pulmonary nodules. However, its use is not generalized in clinical practice, particularly after the introduction and widespread use of PET/CT, which also provides functional information [5]. Comparison between PET/CT and contrast-enhanced CT for the evaluation of solitary pulmonary nodules has been studied on small series favoring PET/CT over dynamic CT. Christensen et al [36] showed sensitivities and specificities of 100% and 29% for dynamic contrast-enhanced CT versus 96% and 76% on PET/CT. Yi et al showed a sensitivity, specificity, and accuracy of 96%, 88%, and 93% for PET/CT versus 81%, 93%, and 85% for dynamic CT, respectively [5,32]. For suspicious solid nodules ≥0.8 cm, Fleischner Society and ACCP guidelines recommend PET/CT as the preferred functional imaging technique on their management algorithms [2,9].

Variant 3: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule equal to or greater than 6 mm on chest CT. Next imaging study.

C. CT Chest With IV Contrast

There is not enough high-quality evidence to support the use of chest CT with IV contrast in the initial evaluation of patients presenting with incidentally detected indeterminate pulmonary nodules ≥6 mm on chest CT. Dual-energy CT (DECT) has been proposed as a technique to measure the enhancement of incidental pulmonary nodules. On DECT, a virtual nonenhanced image can be obtained from a contrast-enhanced study. Some authors have suggested that dual-kilovolt peak CT may be useful in the identification of benign pulmonary nodules with low levels of calcification [26,37]. Chae et al [38] prospectively evaluated the clinical utility of DECT in 49 patients with solitary pulmonary nodules. The average nodule diameter was 24.8 ± 11.8 mm. The accuracy for malignancy using CT numbers on iodine-enhanced images was similar to that using the degree of enhancement (sensitivity 92% and 72%; specificity 70% and 70%, accuracy 82.2% and 71.1%, respectively). A multicenter study of 240 incidental pulmonary nodules aimed to evaluate if dual-kilovolt peak analysis was useful in the identification of benign pulmonary nodules. Results showed that the use of unenhanced DECT to evaluate attenuation values changes was not reliable for differentiating benign from malignant nodules (higher chance of a benign nodule containing calcium). A detailed breakdown of each nodule size is not reported, but the mean size ± SD was 17.8 ± 6.5 mm for malignant nodules and 14.0 ± 4.3 mm for benign nodules [38].

Cancer staging, an incidental mass workup, and nodules with associated lymphadenopathy fall outside of the scope of this document. Pulmonary arteriovenous malformations (PAVM) are vascular structures resulting from abnormal communication between pulmonary arteries and veins that bypass the pulmonary capillary bed. PAVMs can be confused with pulmonary nodules [39]. In the case a nodule is suspected to represent a PAVM, please refer to the ACR Appropriateness Criteria® topic on "Clinically Suspected Pulmonary Arteriovenous Malformation (PAVM)" [39].

Variant 3: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule equal to or greater than 6 mm on chest CT. Next imaging study.

D. FDG-PET/CT Whole Body

For incidental indeterminate solid pulmonary nodules >0.8 cm, Fleischner Society guidelines recommend FDG-PET/CT as one of the potential next steps to help determine the nodule's likelihood of malignancy. Please refer to Appendix 2 for details [9]. ACCP guidelines recommend functional imaging, preferably with FDG-PET/CT, for the evaluation of solid indeterminate

pulmonary nodules ≥0.8 cm when the pretest probability of malignancy is low to moderate (5%-65%). Guidelines emphasize clinicians should discuss risks and benefits of management strategies with patients and incorporate their preferences [2].

The role of FDG-PET/CT in the differentiation of benign from malignant nodules has been extensively studied and relies on measuring glucose metabolism, which is typically elevated on malignant lesions. Reported sensitivities and specificities range from 88% to 96% and 77% to 88%, respectively [1,5,32]. Given PET limited spatial resolution, its use in the management of incidental pulmonary nodules is suggested for nodules >0.8 cm [2,9,40]. Nodule size (generally >0.8 cm), nodule attenuation, selected patient cohorts, how a malignant nodule is defined, and technical factors vary by study and should be considered when making conclusions about reported sensitivities and specificities.

PET/CT and contrast-enhanced CT have been compared for the evaluation of solitary pulmonary nodules on small series, with results favoring PET/CT over dynamic CT. Christensen et al [36] showed sensitivities and specificities of 96% and 76% for PET/CT versus 100% and 29% for dynamic CT. Yi et al showed sensitivity, specificity, and accuracy of 96%, 88%, and 93% for PET/CT versus 81%, 93%, and 85% for dynamic CT, respectively [5,32].

False-negative results on PET/CT go beyond small nodule size (<0.8 cm). Certain malignant tumors show low metabolic activity including carcinoid and adenocarcinoma regardless of size (those with predominant ground-glass component, small solid components, and mucinous type). PET/CT is not a reliable test to distinguish benign from malignant ground-glass nodules (or part-solid nodules with small solid components). Because of the indolent behavior of ground-glass nodules, PET/CT sensitivity is low and follow-up chest CT is preferred [9,26-28]. Defective technique can also result in false-negative studies [4,41,42].

False-positive results on PET/CT also exist, mostly infectious and inflammatory lesions and less frequently sarcoidosis and rheumatoid nodules. Decreased FDG-PET/CT specificity to differentiate benign from malignant nodules has been recognized in regions with high prevalence of lung infections and reported as low as 25% in areas of endemic tuberculosis [40,43]. A meta-analysis of 70 studies showed FDG-PET/CT specificity adjusted for endemic infectious lung disease was 61% (95% CI, 49%-72%) compared to nonendemic regions 77% (95% CI, 73%-80%) [40,44]. Reyes et al [45] conducted a retrospective study comparing 351 biopsy-proven granulomatous and malignant nodules in a coccidioidal endemic region. Authors found that an elevated maximum standardized uptake value (SUV_{max}) was the only distinguishing feature between benign and malignant nodules. All nodules with SUV_{max} >5.9 were malignant, but there was overlap in nodules with SUV_{max} <5.9. Using an SUV_{max} <5.9, the sensitivity and specificity were 69% and 100%, respectively. This limitation should be recognized in endemic areas because it could alter the choice of next steps to more conservative options such as short-term follow-up CT.

PET overutilization has been described. Nair et al [40] evaluated the appropriateness of PET and PET/CT practice patterns in the evaluation of pulmonary nodules detected in the National Lung Screening Trial. Appropriate use was defined as studies performed for nodules ≥0.8 cm given PET limited spatial resolution. The authors found that 21% of diagnostic PET done on patients with a positive screen were inappropriate, and 86% of PET scans for nodules <0.8 cm were performed despite not being recommended by a radiologist. For nodules >0.8 cm, >50% of PET scans were

also ordered despite not being recommended by radiologists, suggesting less conservative management by other practitioners managing pulmonary nodules. Clear radiologist recommendations and multidisciplinary discussions could encourage appropriate use of PET.

Variant 3: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule equal to or greater than 6 mm on chest CT. Next imaging study.

E. FDG-PET/MRI Whole Body

There is no relevant literature to support the use of PET/MRI in the initial evaluation of incidentally detected pulmonary nodules. The use of FDG-PET/MRI in humans was first described in the early 2000s. PET/MRI integrates anatomic and functional MRI data with the metabolic information of PET. Interest around PET/MRI includes functional information and higher soft-tissue contrast resolution. An international survey of active whole-body PET/MRI sites showed oncology as its main application. Perceived challenges to its widespread use included study duration (2 times longer than a typical PET/CT), lack of standardized protocols, and challenges with interpretation (>80% sites had radiologist and nuclear medicine physicians jointly reporting as opposed to 40% for PET/CT) [46]. When imaging the lungs, PET/MRI faces the same challenges as lung MRI. Small nonavid nodules are usually missed, and finding precise anatomic correlates for areas of lung uptake can be difficult.

Most of the PET/MRI literature is limited to oncologic patients. Reported sensitivities of PET/MRI in detecting nodules on a nodule basis ranges between 30% and 83% [47]. Small series on oncologic patients show that the detection of non-FDG-avid nodules <5 mm on PET/MRI is inferior to PET/CT [48,49]. A retrospective study of 126 patients with primary abdominal malignancies compared PET/MRI nodule detection to PET/CT or chest CT, along with the impact of missed nodules on clinical management. PET/MRI sensitivity and specificity for nodule detection was 12.1% and 69.8%, respectively. Size was the most relevant factor in nodule detection with <15% for nodules ≤5 mm and >70% for nodules ≥7 mm. Of the missed nodules, 22.3% showed interval growth and were presumed metastasis. Even though none of the misses influenced clinical management, the authors emphasized the majority of patients (87%) had advanced-stage cancers and advised caution in clinical practice if detection of lung metastasis would alter a patient's management [47]. Another series of 51 oncologic patients evaluated the outcome of missed nodules on PET/MRI compared to PET/CT, with 31% of the nodules missed on PET/MRI. At follow-up, 21.4% of the missed nodules were rated malignant. This resulted in one patient being upstaged from tumor stage I to IV [50].

Further advances on PET/MRI are needed before it is implemented in clinical practice, and current research points toward its use in oncology as opposed to incidental pulmonary nodule characterization.

Variant 3: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule equal to or greater than 6 mm on chest CT. Next imaging study.

F. Image-Guided Transthoracic Needle Biopsy

For incidental indeterminate solid pulmonary nodules >0.8 cm, tissue sampling is a potential next step in nodule evaluation, especially if there is a high pretest probability of malignancy. Please refer to Appendix 2 for details [9]. ACCP guidelines and management algorithms include CT surveillance, PET/CT, biopsy, or standard staging evaluation as potential next steps in the

evaluation of solid indeterminate pulmonary nodules ≥0.8 cm based on a variety of factors, including nodule size, risk factors for lung cancer, pretest probability of malignancy, and surgical risk [2]. This procedure was rated by the panel as may be appropriate in order to favor less invasive options in the initial evaluation of these nodules.

Procedures available for tissue sampling include imaged-guided biopsies, transbronchial biopsy guided by electromagnetic navigation and endobronchial ultrasound, and minimally invasive surgery. Factors affecting the procedure of choice should not only be limited to nodule size but also nodule attenuation and location, the patient's comorbidities and preferences, and estimated pretest probability of malignancy. A multidisciplinary approach aligned with current guidelines is strongly encouraged when deciding which procedure would be most appropriate for each patient, along with patient's preferences after benefits and harms are discussed [2,9,28]. A detailed discussion of semi-invasive or invasive techniques for tissue sampling falls outside of the scope of this image-focused document. ACCP and British Thoracic Society guidelines might be useful for a more in-depth discussion of when each procedure might be appropriate, along with their benefits and harms [2,28].

Tissue sampling helps differentiate benign from malignant nodules. Image-guided TNB is usually performed under CT guidance, although ultrasound can be used based on a lesion's size and location. The sensitivity of TNB is multifactorial with nodule size, location, needle size, and number of passes affecting success rates [2]. Reported diagnostic accuracy rates range from 65% to 96% [51]. An analysis of 11 studies between 2005 and 2011 showed a median of nondiagnostic results of 6% (range <1%-55%) and sensitivity for identifying malignancy ranging from 70% to >90%. The median prevalence of malignancy in those studies was 68%. A meta-analysis of 25 studies evaluating the diagnostic accuracy and complication rates of 2,922 CT-guided lung biopsies of nodules ≤2 cm showed a pooled technical success rate and diagnostic accuracy of 94% and 90%, respectively [52]. Although some studies have shown decreased accuracy with smaller lesion size, results range from 52% to 95% for nodules <1 cm [53]. A single institution retrospective study evaluated the diagnostic yield of CT-guided biopsy of 133 nodules measuring 6 to 10 mm. The yield for malignant and benign lesions was 93% and 65%, respectively. The diagnostic yield of the part-solid or ground-glass nodules was 93%. A final benign diagnosis was the strongest independent risk factor for biopsy failure. Fine-needle aspiration (FNA) was also an independent risk factor for biopsy failure [53]. The authors discuss that improved success rates in recent studies may reflect advances in technique and increasing experience. A different meta-analysis showed pooled sensitivity and specificity for CT-guided percutaneous FNA biopsy of 90% and 99%, respectively, and for percutaneous core-needle biopsy 95% and 99%, respectively [54,55]. Lower sensitivities were reported in studies analyzing nodules ≤15 mm [2]. Lower sensitivity in TNB for subsolid and ground-glass nodules have been described, but results are variable with diagnostic yield ranges of 51% to >90% [2].

The most common complication of TNB is pneumothorax, and rates vary in series based on technique and study design. Two meta-analysis reported pooled rates of pneumothorax and hemoptysis of 19% to 25.3% and 4.1% to 12%, respectively [52,56]. Other studies report pneumothorax in 16% to 45% of cases and pneumothorax requiring a chest tube in 1.8% to 15% [52,53,56]. A meta-analysis of 46 studies from 2010-2015 described complication rates of CT-guided core-needle and FNA biopsy. They found that minor complications were more common in FNA, major complications were rare, and that smaller nodules, larger needle diameter, and

increased transverse lung were risk factors for FNA complications. Complication rate for core biopsy was 38.8% versus 24.0% for FNA ($P < .001$). Major complications were 5.7% and 4.4% for core biopsy and FNA, respectively (no statistical significance). Pooled complication rates for CT-guided core-needle biopsy included pneumothorax 25.3%, pneumothorax requiring intervention 5.6%, pulmonary hemorrhage 18.0%, and hemoptysis 4.1%. For FNA, complication rates were lower: 18.8%, 4.3%, 6.4%, and 1.7%, respectively [56]. A retrospective single-institution study of 550 patients found no statistical differences between pneumothorax rates between 18-G and 20-G CT-guided pulmonary nodule biopsies (25.6% versus 28.7%, respectively). Chest tube insertion rate for 18-G and 20-G was 4.8% versus 5.6%, respectively. Diagnostic adequacy was also not significantly different at 95% versus 93% for 18-G and 20-G, respectively. Multiple logistic regression analysis demonstrated emphysema along the biopsy path and nodule distance from the pleural surface ≥4 cm as independent risk factors for pneumothorax [51]. Other reported risk factors for pneumothorax include older age, chronic obstructive pulmonary disease, and transversing fissures [2].

A negative biopsy result does not exclude malignancy, but TNB is valuable when a definite benign diagnosis is confirmed. A biopsy result can also be nonspecific benign or nondiagnostic, in which case continued surveillance or repeat biopsy need to be considered depending on clinical concern for malignancy and the patient's comorbidities and preferences.

Variant 3: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule equal to or greater than 6 mm on chest CT. Next imaging study.

G. MRI Chest Without IV Contrast

There is no relevant literature to support the use of MRI chest in the evaluation of incidentally detected indeterminate pulmonary nodules. MRI has been increasingly studied as an alternative method in the evaluation of incidental pulmonary nodules over the last decades, with reported sensitivities ranging from 26% to 96% for various MRI sequences [54]. Major limitations for accurate nodule characterization include artifact from respiratory and cardiac motion and poor image contrast in lung MRI.

Motion artifact in pulmonary MRI results from longer sequence acquisition times compared to CT. Faster sequences and techniques have been studied to address this problem [57]. A small series by Heye et al [58] using a fast sequence reported a nodule detection rate of 45.5% compared to CT, along with a high number of false-positive nodules related to motion artifact. Nodule size is another well-known limiting factor for many MRI sequences.

Several small series have compared the diagnostic performance of specific MRI sequences to CT for the detection of nodules, with reported sensitivities of 100% only for nodules >10 mm and 73% to 96% for smaller nodules [54,59,60]. Studies evaluating the performance of diffusion weighted imaging (DWI) in lung nodule characterization report sensitivities of 33.3% to 98%, specificities of 36% to 97.1%, and accuracy of 50% to 94%. Nodule size impacts performance, with Regier et al reporting sensitivities of 43.8% for nodules ≤5 mm, 86.4% for nodules 6 to 9 mm, and 97% for nodules ≥10 mm [54,61]. A recent meta-analysis of 37 studies compared the diagnostic performance of FDG-PET and DWI in the differentiation of benign and malignant nodules. Only six of the included studies compared DWI to PET/CT in the same patient population. DWI had a pooled sensitivity and specificity of 83% and 91%, respectively, compared with 78% and 81% for PET/CT ($P = .01$ and $P = .056$, respectively). DWI area under the curve was 0.93 versus 0.86 for

PET/CT (*P* = .001). It is important to note that the median lesion size was 18.5 mm on PET/CT studies, 22 mm on DWI studies, and not reported in several studies [62]. Other investigators have aimed to compare MRI's ability to distinguish benign from malignant part-solid nodules and predict their aggressiveness to that of CT and PET/CT. A pilot study of 32 lesions showed potential of certain parameters to discriminate between malignant and benign nodules and predict adenocarcinomas subtypes, but sample size limited the ability to show statistical significance for multiple parameters [63].

Overall, MRI might have a future role as a complementary tool in the stratification of incidental pulmonary nodules, possibly multiparametric MRI, but further research and validation studies are required before MRI is implemented in clinical practice. Current pulmonary nodule guidelines do not include MRI in the management algorithms for incidental pulmonary nodules [2,9].

Variant 3: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule equal to or greater than 6 mm on chest CT. Next imaging study.

H. MRI Chest Without and With IV Contrast

There is no relevant literature to support the use of dynamic MRI chest in the evaluation of incidentally detected indeterminate pulmonary nodules. MRI has been increasingly studied as an alternative method in the evaluation of incidental pulmonary nodules over the last decades, with reported sensitivities ranging from 26% to 96% for various MRI sequences [54]. Major limitations for accurate nodule characterization include artifact from respiratory and cardiac motion and poor image contrast in lung MRI, which are addressed on the MRI Chest Without IV Contrast section.

Similar to dynamic contrast-enhanced CT, dynamic MRI techniques have been proposed to differentiate benign from malignant pulmonary nodules. Reported sensitivities range from 52% to 100%, specificities from 17% to 100%, and accuracies from 58% to 96% [54,64]. Factors contributing to the wide ranges include variable study design, different sequences studied, and lower performance in cohorts living in areas with high prevalence of active infection. The authors have looked into improving the performance of dynamic contrast-enhanced MRI by adding semiquantitative analysis [65] or combining it with additional sequences, with a small series showing improved specificity and minimal improved accuracy in differentiating benign from malignant solitary nodules [54,66].

Overall, MRI might have a future role as a complementary tool in the stratification of incidental pulmonary nodules, possibly multiparametric MRI, but further research and validation studies are required before MRI is implemented in clinical practice. Current pulmonary nodule guidelines do not include MRI in the management algorithms for incidental pulmonary nodules [2,9].

Variant 3: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule equal to or greater than 6 mm on chest CT. Next imaging study.

I. Radiography Chest

There is no relevant literature to support the use of chest radiographs in the evaluation or follow-up of incidentally detected indeterminate pulmonary nodules on chest CT. Radiograph sensitivity for detecting nodules is low, with a significant number of nodules missed [5]. Most nodules <1 cm are not visible in chest radiographs [9]. In addition, radiographs lack the resolution to adequately characterize nodules.

Variant 4: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on incomplete thoracic CT (eg, CT abdomen, neck, spine, etc). Next imaging study.

Lungs are partially seen on CT from other body parts including neck, spine, heart, and abdomen. Pulmonary nodules are frequently encountered on these studies and are described as the most common incidental finding by some authors [67-69]. Reported nodule incidence ranges from 8% to 23% for coronary CT angiography [7,69,70], 16.4% to 28.2% for patients undergoing CT for transcatheter aortic valve implantation [67,68,71], and 2.5% to 39.1% for abdominal CTs [72-74].

The most updated Fleischner Society guidelines address the management of nodules found on incomplete thoracic CT. Please refer to Appendix 3 for details.

Variant 4: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on incomplete thoracic CT (eg, CT abdomen, neck, spine, etc). Next imaging study.

A. CT Chest Without IV Contrast

For incidental indeterminate pulmonary nodules found on incomplete thoracic CT, Fleischner Society guidelines recommend a follow-up complete chest CT for nodules ≥6 mm at different time intervals ranging from as early as possible to 12 months depending on nodule size, characteristics, and the patient's clinical risk of malignancy [9]. For most nodules <6 mm, no follow-up is recommended given the low likelihood of malignancy. Exceptions for nodules <6 mm are likely the same as for solid nodules <6 mm detected on chest CT, including suspicious features that increase the cancer risk to the 1% to 5% range. Please refer to Appendix 3 for details.

CT is widely recognized as the modality of choice to evaluate pulmonary nodules. Nodule detection and characterization on CT is directly related to image quality and therefore technique, with reported detection sensitivities ranging from 30% to 97% [20]. Factors associated with increased sensitivity include thinner CT sections, nodule location and larger size, and nodule attenuation [20]. Guidelines for nodule management recommend routine use of contiguous thin sections (≤1.5 mm) and reconstructed multiplanar images to ensure adequate nodule characterization, particularly for nodules with a ground-glass attenuation component. If the initial CT was performed with thick sections, obtaining the follow-up CT with ≤1.5 mm sections is encouraged. Low-dose technique is recommended for CTs performed to follow lung nodules [9]. Standardization of acquisition and reconstruction CT protocols will ideally result in more accurate comparisons by reducing the risk of errors measuring nodule size, attenuation, and volume [9,27]. IV contrast is not required to identify, characterize, or determine stability of pulmonary nodules in clinical practice [27], which is also supported in lung cancer screening in which IV contrast is not used.

Certain nodule characteristics suggestive of benign etiology are better appreciated by CT and can avoid additional workup. For example, diffuse, central, laminated, or popcorn calcifications patterns are predictors of benign etiology ([OR] = 0.07–0.20) [28]. Macroscopic fat is another indicator of benign etiology typical of hamartomas, which cannot be appreciated on radiographs. The mean attenuation value of indeterminate benign and malignant nodules on unenhanced CT is not significantly different and therefore not useful in their differentiation. However, multiple imaging features that increase the risk of malignancy are best characterized on CT, including nodule size, morphology, location, multiplicity, or the presence of emphysema or fibrosis. Unsuspected

associated processes such as lymphadenopathy can sometimes be detected on CT, and CT can help with planning next steps such as biopsy when indicated [2].

Variant 4: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on incomplete thoracic CT (eg, CT abdomen, neck, spine, etc). Next imaging study.
B. CT Chest Without and With IV Contrast

There is no relevant literature to support the use of dynamic contrast-enhanced CT in the evaluation of incidentally detected indeterminate pulmonary nodules encountered on incomplete thoracic CT.

Variant 4: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on incomplete thoracic CT (eg, CT abdomen, neck, spine, etc). Next imaging study.
C. CT Chest With IV Contrast

There is no relevant literature to support the use of contrast-enhanced CT in the evaluation of incidentally detected indeterminate pulmonary nodules encountered on incomplete thoracic CT. Cancer staging, an incidental mass workup, and nodules with associated lymphadenopathy fall outside of the scope of this document.

Variant 4: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on incomplete thoracic CT (eg, CT abdomen, neck, spine, etc). Next imaging study.
D. FDG-PET/CT Whole Body

There is no relevant literature to support the use of FDG-PET/CT in the evaluation of incidentally detected indeterminate pulmonary nodules encountered on incomplete thoracic CT.

Variant 4: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on incomplete thoracic CT (eg, CT abdomen, neck, spine, etc). Next imaging study.
E. Image-Guided Transthoracic Needle Biopsy

There is no relevant literature to support the use of image-guided TNB in the evaluation of incidentally detected indeterminate pulmonary nodules encountered on incomplete thoracic CT.

Variant 4: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on incomplete thoracic CT (eg, CT abdomen, neck, spine, etc). Next imaging study.
F. MRI Chest Without IV Contrast

There is no relevant literature to support the use of MRI chest without IV contrast in the evaluation of incidentally detected indeterminate pulmonary nodules encountered on incomplete thoracic CT.

Variant 4: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on incomplete thoracic CT (eg, CT abdomen, neck, spine, etc). Next imaging study.
G. MRI Chest Without and With IV Contrast

There is no relevant literature to support the use of dynamic MRI chest in the evaluation of incidentally detected indeterminate pulmonary nodules encountered on incomplete thoracic CT.

Variant 4: Adult greater than or equal to 35 years of age. Incidentally detected indeterminate pulmonary nodule on incomplete thoracic CT (eg, CT abdomen, neck, spine,

etc). Next imaging study.

H. Radiography Chest

There is no relevant literature to support the use of chest radiographs in the evaluation of incidentally detected indeterminate pulmonary nodules encountered on incomplete thoracic CT. Radiograph sensitivity for detecting pulmonary nodules is low, with a significant number of nodules missed [5]. Most nodules <1 cm are not visible in chest radiographs [9]. In addition, radiographs lack the resolution to adequately characterize pulmonary nodules.

Summary of Recommendations

- **Variant 1**: CT chest without IV contrast is usually appropriate as the next imaging study in the evaluation of incidentally detected indeterminate pulmonary nodules on chest radiographs if there are no prior studies to confirm the nodule has been stable for 2 years. If the nodule has been stable for 2 years, no further workup is recommended.
- **Variant 2**: CT chest without IV contrast may be appropriate as the next imaging study in the evaluation of incidentally detected indeterminate pulmonary nodules measuring <6 mm on chest CT. This optional follow-up CT can be considered when a nodule <6 mm has characteristics that increase the cancer risk to the 1% to 5% range, including suspicious morphology, upper lobe location, or both, in patients who are at high risk. The proposed follow-up CT time varies by nodule attenuation (see Appendix 1 for details).
- **Variant 3**: CT chest without IV contrast is usually appropriate as the next imaging study in the evaluation of incidentally detected indeterminate pulmonary nodules measuring ≥6 mm on chest CT, regardless of nodule attenuation. The proposed follow-up CT time varies by nodule size and attenuation (see Appendix 2 for details). FDG-PET/CT whole body is usually appropriate as the next imaging study in the evaluation of incidentally detected indeterminate pulmonary nodules that are solid and measure >8 mm on chest CT. These procedures are equivalent alternatives for solid nodules >8 mm. (ie, only one procedure will be ordered to provide the clinical information to effectively manage the patient's care).
- **Variant 4**: CT chest without IV contrast is usually appropriate as the next imaging study in the evaluation of incidentally detected indeterminate pulmonary nodules measuring ≥6 mm encountered on incomplete thoracic CT. The proposed follow-up CT time varies by nodule size, appearance, and the patient's clinical risk for malignancy (see Appendix 3 for details).

Supporting Documents

The evidence table, literature search, and appendix for this topic are available at https://acsearch.acr.org/list. The appendix includes the strength of evidence assessment and the final rating round tabulations for each recommendation.

For additional information on the Appropriateness Criteria methodology and other supporting documents, please go to the ACR website at https://www.acr.org/Clinical-Resources/Clinical-Tools-and-Reference/Appropriateness-Criteria.

Appropriateness Category Names and Definitions

Appropriateness Category Name	Appropriateness Rating	Appropriateness Category Definition

Usually Appropriate	7, 8, or 9	The imaging procedure or treatment is indicated in the specified clinical scenarios at a favorable risk-benefit ratio for patients.
May Be Appropriate	4, 5, or 6	The imaging procedure or treatment may be indicated in the specified clinical scenarios as an alternative to imaging procedures or treatments with a more favorable risk-benefit ratio, or the risk-benefit ratio for patients is equivocal.
May Be Appropriate (Disagreement)	5	The individual ratings are too dispersed from the panel median. The different label provides transparency regarding the panel's recommendation. "May be appropriate" is the rating category and a rating of 5 is assigned.
Usually Not Appropriate	1, 2, or 3	The imaging procedure or treatment is unlikely to be indicated in the specified clinical scenarios, or the risk-benefit ratio for patients is likely to be unfavorable.

Relative Radiation Level Information

Potential adverse health effects associated with radiation exposure are an important factor to consider when selecting the appropriate imaging procedure. Because there is a wide range of radiation exposures associated with different diagnostic procedures, a relative radiation level (RRL) indication has been included for each imaging examination. The RRLs are based on effective dose, which is a radiation dose quantity that is used to estimate population total radiation risk associated with an imaging procedure. Patients in the pediatric age group are at inherently higher risk from exposure, because of both organ sensitivity and longer life expectancy (relevant to the long latency that appears to accompany radiation exposure). For these reasons, the RRL dose estimate ranges for pediatric examinations are lower as compared with those specified for adults (see Table below). Additional information regarding radiation dose assessment for imaging examinations can be found in the ACR Appropriateness Criteria® Radiation Dose Assessment Introduction document.

Relative Radiation Level Designations

Relative Radiation Level*	Adult Effective Dose Estimate Range	Pediatric Effective Dose Estimate Range
O	0 mSv	0 mSv
☢	<0.1 mSv	<0.03 mSv
☢☢	0.1-1 mSv	0.03-0.3 mSv
☢☢☢	1-10 mSv	0.3-3 mSv
☢☢☢☢	10-30 mSv	3-10 mSv
☢☢☢☢☢	30-100 mSv	10-30 mSv

*RRL assignments for some of the examinations cannot be made, because the actual patient doses in these procedures vary as a function of a number of factors (e.g., region of the body exposed to ionizing radiation, the imaging guidance that is used). The RRLs for these examinations are designated as "Varies."

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Disclaimer

The ACR Committee on Appropriateness Criteria and its expert panels have developed criteria for determining appropriate imaging examinations for diagnosis and treatment of specified medical condition(s). These criteria are intended to guide radiologists, radiation oncologists and referring physicians in making decisions regarding radiologic imaging and treatment. Generally, the complexity and severity of a patient's clinical condition should dictate the selection of appropriate imaging procedures or treatments. Only those examinations generally used for evaluation of the patient's condition are ranked. Other imaging studies necessary to evaluate other co-existent diseases or other medical consequences of this condition are not considered in this document. The availability of equipment or personnel may influence the selection of appropriate imaging procedures or treatments. Imaging techniques classified as investigational by the FDA have not been considered in developing these criteria; however, study of new equipment and applications should be encouraged. The ultimate decision regarding the appropriateness of any specific radiologic examination or treatment must be made by the referring physician and radiologist in light of all the circumstances presented in an individual examination.

Appendix 1. Incidentally detected indeterminate pulmonary nodule <6 mm on chest CT

Nodule Type	Routine follow-up recommended	Exceptions	Comment
Solid	No*	Optional follow-up CT at 12 months** when nodule features increase cancer risk to the 1% to 5% range, including suspicious morphology, upper lobe location, or both, in patients at high risk	*Regardless of patient's risk factors. Screening trials show that the risk of cancer in nodules <6 mm is <1%, even in patients at high risk for lung malignancy **After considering patient's preferences and comorbidities
Ground-glass	No	Optional follow-up CT at 2- and 4-years* for nodules close to 6 mm in size with suspicious morphology or other risk factors	*This data comes from Asian populations, where near 1% of ground-glass nodules may progress to adenocarcinoma over many years
Part-solid	No		Because of the difficulty defining the solid component in nodules of this size, the recommendation is to treat part-solid nodules <6 mm the same way

			as ground-glass nodules <6 mm

Appendix 2. Incidentally detected indeterminate pulmonary nodule ≥6 mm on chest CT

Nodule Type	Routine follow-up recommended	Exceptions	Comments
Solid 6 to 8 mm	Initial follow-up CT at 6 to 12 months*	None	*Regardless of the patient's risk factors Timing can be selected based on nodule size, morphology, and patient preference
Solid >8 mm	Follow-up CT at 3 months, PET/CT, tissue sampling, or a combination	None	*Regardless of the patient's risk factors. Decision of next step should be based on nodule size, morphology, and patient's comorbidities and preferences
Ground-glass ≥6 mm	Initial follow-up CT at 6 to 12 months*‡		*To evaluate for persistence or resolution ‡For ground-glass nodules with suspicious features such as larger size (>1 cm) and internal bubbly lucencies, the initial follow-up CT is recommended at 6 months
Part-solid ≥6 mm	Initial follow-up CT at 3 to 6 months*		*To evaluate for persistence or resolution

Appendix 3. Incidentally detected indeterminate pulmonary nodule on incomplete thoracic CT (eg, CT abdomen, neck, spine, etc)

Nodule Type	Routine follow-up recommended	Exceptions	Comments
<6 mm	No*	Optional follow-up CT at 12 months* when nodule features	*For most nodules. Screening trials show that the risk of cancer in

		increase cancer risk to the 1% to 5% range, including suspicious morphology, upper lobe location, or both	nodules <6 mm is <1%, even in patients at high risk for lung malignancy
6-8 mm	Follow-up complete chest CT at 3 to 12 months*		*To confirm stability and evaluate for additional findings. Calculate time based on patient's clinical risk for malignancy
>8 mm or very suspicious	Follow-up complete chest CT as early as possible		

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