A solitary pulmonary nodule is defined as “a round opacity, at least moderately well-marginated and no greater than 3 cm in maximum diameter.”\(^1\) The adjective *small* is occasionally used to characterize a nodule with a maximum diameter of less than 1 cm.\(^2\) With the increasing use of multidetector CT (MDCT), small nodules are being detected with increasing frequency. In one screening study, the majority of patients who were screened had at least one nodule.\(^2\) Although most incidentally discovered nodules are benign (usually the sequelae of pulmonary infection), malignancy remains an important consideration in the differential diagnosis of solitary pulmonary nodules (Table 1). According to the American Cancer Society,\(^3–5\) 1 in 13 men and 1 in 16 women will be diagnosed with lung cancer and it is estimated that 20% to 30% of these patients will present with a solitary pulmonary nodule. Because many patients with early-stage lung cancer can present with a solitary pulmonary nodule, one of the main goals of imaging is to accurately differentiate malignant from benign lesions. Techniques for noninvasive image-based assessment and management of these nodules have rapidly evolved recently in large part because of data from ongoing screening studies and from thin-slice helical MDCT studies examining nodule morphology.

MDCT has improved nodule detection and characterization by increasing spatial and temporal resolution and decreasing misregistration artifacts. Typical reconstructions comprise 3- to 5-mm slice collimation for a nontargeted field of view. Obtaining images through the region of interest using a slice collimation of 1 to 1.5 mm improves spatial resolution and is useful in reducing partial volume averaging. If a 1.25-mm slice collimation has been used, as is common in CT angiography protocols to evaluate for pulmonary emboli, differentiating a vessel from a small central nodule is difficult and can be addressed with postprocessing techniques, such as maximum intensity projection, volume rendering, and cine viewing.\(^6–8\) This article reviews the role of imaging in the detection and characterization of solitary pulmonary nodules. Strategies for evaluating and managing solitary pulmonary nodules are also discussed.

**CLINICAL ASSESSMENT**

How a nodule is managed depends on the probability of malignancy. Clinical factors associated with an increased risk of developing lung cancer include older age, presenting symptoms, smoking, and exposure to asbestos, uranium, or radon. In terms of clinical presentation, patients with hemoptysis are at increased risk for malignancy.\(^9\) Past medical history is important as there is an increased risk of lung cancer in patients with
a history of a prior neoplasm and in patients with pulmonary fibrosis. Family history also plays a role in determining the likelihood of malignancy. In this regard, a susceptibility gene to lung cancer has been reported and the risk of developing lung cancer increases in patients who have a first-degree relative with lung cancer. The overall assessment of a patient’s risk for malignancy is important in the decision analysis concerning management. For example, in a patient presenting with fever, cough, and a new focal pulmonary opacity, radiographic follow-up to resolution may be all that is necessary to exclude malignancy and confirm a diagnosis of round pneumonia. However, if a new nodule is detected in a patient with a prior history of pulmonary sarcoma, the probability that this is a metastasis is high and tissue should be obtained for diagnosis (Fig. 1). For patients with a prior history of cancer, Ginsberg and colleagues showed that nodules 5 mm or smaller were malignant in 115 of 275 (42%) patients undergoing video-assisted thoracoscopic resection of nodules. To identify independent predictors of malignancy, quantitative models have been developed using multiple logistic regression analysis. Independent predictors of malignancy include older age, current or past smoking history, and history of extrathoracic cancer more than 5 years before nodule detection.

### RADIOLOGICAL EVALUATION

Although CT detects an increasing number of solitary pulmonary nodules either incidentally or as part of a lung cancer screening study, many nodules are still initially detected on chest radiographs. If the nodule is diffusely calcified or if a comparison with older radiographs shows stability in size for more than 2 years, the nodule is presumed to be benign and no further evaluation is recommended. However, many nodules require

<table>
<thead>
<tr>
<th>Type of Cause</th>
<th>Disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neoplastic malignant</td>
<td>Primary lung malignancies (non–small cell, small cell, carcinoid, lymphoma); solitary metastasis</td>
</tr>
<tr>
<td>Benign</td>
<td>Hamartoma; arteriovenous malformation</td>
</tr>
<tr>
<td>Infectious</td>
<td>Granuloma; round pneumonia; abscess; septic embolus</td>
</tr>
<tr>
<td>Noninfectious</td>
<td>Amyloidoma; subpleural lymph nodule; rheumatoid nodule; Wegener granulomatosis; focal scarring; infarct</td>
</tr>
<tr>
<td>Congenital</td>
<td>Sequestration; bronchogenic cyst; bronchial atresia with mucoid impaction</td>
</tr>
</tbody>
</table>

Fig. 1. Sixty-eight-year-old woman with a prior left pneumonectomy for a sarcoma. (A) Contrast-enhanced CT and (B) positron emission tomography/CT show a hypometabolic irregular right upper lobe nodule with standardized uptake value of 1.4. With advances in positron emission tomography technology, evaluation of nodules as small as 7 mm is possible. However, a negative positron emission tomography does not preclude malignancy. Because of the high clinical suspicion of malignancy with regards to the age of the patient and history of prior lung malignancy, transthoracic needle aspiration biopsy was performed and revealed an adenocarcinoma.
further imaging evaluation. MDCT optimally evaluates morphologic characteristics of the nodule and is useful in assessing for growth on serial studies. Nodules may be missed on MDCT because of a variety of factors, including central location, small size, low attenuation, and location in the lower lobes or adjacent to another abnormal pulmonary opacity, such as inflammatory change. Difficulty with interpretation also occurs with CT as it may not be possible to determine whether a small opacity is a nodule, a vessel, or due to partial volume averaging of adjacent intrathoracic structures. However, the use of thin-section CT together with postprocessing techniques, such as maximum intensity projection, volume rendering, and cine viewing of images at a picture archiving and communication system workstation, has improved the ability to correctly determine whether a pulmonary opacity is a nodule.

**Nodule Morphology**

Although there is considerable overlap in the morphology and appearance of benign and malignant solitary pulmonary nodules, several morphologic features are useful in assessing a nodule’s malignant potential. These features include the size, margins, contour, internal morphology (attenuation, wall thickness in cavitary nodules, air bronchograms), presence of satellite nodules, halo sign, reverse halo sign, and growth rate.

The risk of malignancy correlates with nodule size. However, small nodule size does not exclude malignancy. In this regard, the widespread use of MDCT, coupled with the recent interest in CT screening for lung cancer, has resulted in the frequent and incidental detection of small nodules (1–5 mm). While the majority of these nodules are benign, studies of resected small nodules have shown that a considerable number are malignant—as high as 42% for patients with a known malignancy undergoing video-assisted thoracoscopic resection of nodules 5 mm or less.

Typically, benign nodules have well-defined margins and a smooth contour while malignant nodules have ill-defined or spiculated margins and a lobular or irregular contour. Lobulation is attributed to differential growth rates within nodules, while the irregular or spiculated margins are usually due to growth of malignant cells along the pulmonary interstitium. However, there is considerable overlap between benign and malignant nodules regarding margins and contour. For example, although a spiculated margin with distortion of adjacent bronchovascular bundles (often described as a sunburst or corona radiata) is highly suggestive with a 90% predictive value of malignancy, benign nodules due to infection/inflammation can also have this appearance (Fig. 2). Additionally, a smooth nodule margin does not exclude malignancy. Up to 20% of primary lung malignancies have smooth contours and well-defined margins and most metastatic nodules typically manifest as smooth margins.

The halo sign is a poorly defined rim of ground-glass attenuation around the nodule (Fig. 3). This halo may represent hemorrhage, tumor infiltration, or perinodular inflammation. Originally described as a sign of invasive aspergillus infection, the CT halo sign may also be seen with bronchioloalveolar carcinoma. Conversely, the reverse halo sign is a focal round area of ground-glass attenuation surrounded by a ring of consolidation (Fig. 4). Described in cryptogenic organizing pneumonia and paracoccidioidomycosis, the reverse halo

![Image](image_url)
sign is histologically due to a greater amount of inflammatory cells in the periphery of the lesion than in the center. In invasive fungal pneumonias, the reverse halo sign is due to infarcted lung with a greater amount of hemorrhage in the peripheral solid ring than in the center ground-glass region.

Fat within a nodule is a characteristic finding of a hamartoma and is detected by CT in up to 50% of these neoplasms (Fig. 5). Rarely, lung metastases in patients with liposarcomas or renal cell cancers can manifest as fat-containing nodules.

Calcification patterns can be useful in determining benignity of a nodule and CT is considerably more sensitive than radiography for detecting calcification in a nodule. However, partial volume averaging can be problematic when thicker sections are obtained, making calcification within a small nodule visually undetectable. In these cases, thin sections (1–3 mm) to improve spatial resolution should be performed to detect calcification. With the introduction of dual-energy CT, simultaneous 80-kV and 140-kV images can be obtained. It has been shown that measurement of CT attenuation values obtained at different kilovolt peaks may be useful in identifying areas of fat, calcium, bone, soft tissue, and iodinated contrast and in evaluating tumor perfusion. However, a multi-institutional trial has shown that dual-energy CT is unreliable for distinguishing benign from malignant nodules.

Common benign patterns of calcification include diffuse, central, laminated, and “popcorn.” However, lung metastases from chondrosarcomas or osteosarcomas can present with “benign” patterns of calcification (Fig. 6). Calcification can be detected in up to 13% of all lung cancers on CT, although the incidence in patients with lung cancer manifesting as nodules less than 3 cm is only 2%. Calcification patterns, such as stippled, eccentric, or amorphous, are indeterminate in etiology as they can be seen in both benign and malignant conditions (Fig. 7).

The widespread use of MDCT images has increased the detection of “subsolid” nodules containing a component of ground-glass attenuation. The “subsolid” category comprises pure...
ground-glass, as well as mixed solid and ground-glass (partly solid) lesions. In the ELCAP (Early Lung Cancer Action Project) study, 19% of positive results on the baseline screening were subsolid. Incidence of malignancy varies according to the degree of soft tissue attenuation. Henschke and colleagues\(^37\) reported rates of malignancy for solid and subsolid nodules as 7% and 34%, respectively. Partly solid nodules had the highest incidence of malignancy (63%) ([Fig. 8](#)) while pure ground-glass nodules had an incidence of malignancy of 18%.

In terms of malignant potential, subsolid nodules have been associated with a spectrum of entities ranging from atypical adenomatous hyperplasia (a premalignant condition), to bronchioloalveolar carcinoma and invasive adenocarcinoma.\(^38\) Atypical adenomatous hyperplasia ([Fig. 9](#)), a putative precursor to bronchioloalveolar carcinoma/adenocarcinoma, is defined by the World Health Organization as a localized proliferation of mild to moderately atypical cells lining involved alveoli and sometimes respiratory bronchioles, resulting in focal lesions in peripheral alveolated lung, usually less than 5mm in diameter and generally in the absence of underlying interstitial inflammation and fibrosis.\(^39\)

Ground-glass nodules less than 1 cm may represent atypical adenomatous hyperplasia or bronchioloalveolar carcinoma. Subsolid nodules greater than 1 cm are more likely to represent bronchioalveolar carcinoma rather than atypical adenomatous hyperplasia. Noguchi and Shimosato\(^38\) graded the spectrum of bronchioalveolar carcinoma and invasive adenocarcinoma pathologically into types A through F, representing various degrees of aggressiveness. This grading system showed that the presence of solid component on CT in a ground-glass nodule is concerning for higher grades of adenocarcinoma.\(^40\) In contradistinction, another study revealed that pure ground-glass opacities were less likely to have invasion and/or metastasis.\(^41\)

Solid nodules have the lowest incidence of malignancy, as many infections, particularly mycoses and tuberculosis, have this appearance. However, despite the lower incidence of malignancy in solid nodules, most primary lung cancers and metastases present as solid nodules.\(^21\)

Cavitation occurs in both infectious/inflammatory conditions as well as in primary and metastatic tumors. Up to 15% of primary lung malignancies cavitate and typically cavitation is seen in squamous cell histology ([Fig. 10](#)). Thick, irregular walls are typically seen in malignant cavitary nodules, whereas smooth, thin walls are seen in benign cavitory lesions.\(^19\) It has been reported that 95% of cavitary nodules with a wall thickness greater than 16 mm are malignant and 92% with a wall thickness less than 4 mm are benign.\(^42,43\) Although these measurements can add value in nodule evaluation, cavity wall thickness cannot be used to reliably differentiate benign and malignant nodules because of cavitary nodules with a wall thickness of 5 to 15 mm, 51% were found to be benign and 49% malignant.\(^43\)

Additional morphologic imaging features that can be used in assessing the malignant or benign potential of solitary pulmonary nodules include the presence of internal luencies, air bronchograms, and satellite nodules. Bronchioalveolar carcinoma can also show small internal luencies due to patent bronchi from lepidic growth of tumor cells ([Fig. 11](#)). In one study, air bronchograms occurred more frequently in malignant nodules (30%) than in benign nodules (6%)\(^44\), and the differential diagnosis includes bronchioalveolar carcinoma, lymphoma, and infection. Satellite nodules, small nodules adjacent to a dominant nodule, are more frequently associated with benign lesions. However, 6% to 16% of patients with lung cancer present with T4-satellite nodules.\(^45–47\)

### Nodule Growth

Nodule growth can be evaluated by reviewing prior films. Malignant nodules may double in volume...
between 30 and 400 days (Fig. 12). Nodules that double in volume in less than 30 days are typically infectious or inflammatory in etiology but may also be seen in lymphoma or rapidly growing metastases (Fig. 13). Nodules that double in volume in greater than 400 days are usually benign neoplasms or sequelae of prior pulmonary infections. In general, the lack of growth over a 2-year period is reliable in determining benignity of a nodule. This criterion does not apply to subsolid nodules because some well-differentiated adenocarcinoma and bronchioloalveolar carcinoma can have doubling times of up to 1346 days. In a screening study analyzing the growth rates of small lung cancers, Hasegawa and colleagues found that approximately 20% (12 of 61) had volume-doubling time of greater than 2 years, typically seen with well-differentiated adenocarcinomas. Interestingly, the volumedoubling time was longer in nonsmokers than in smokers. Of small lung cancers, the longest doubling time was seen in nonsolid lesions, followed by partly solid lesions, and, finally, solid lesions.

Because nodule growth is an important consideration when assessing lesions for malignant potential, the accuracy of growth assessment needs to be addressed. For a nodule to double in volume, the change in nodule diameter is approximately 26%. For a small nodule, this small

Fig. 7. Forty-seven-year-old man with a right upper lobe nodule with a lobular contour in (A) contrast-enhanced CT in lung windows, amorphous calcifications in (B) contrast-enhanced CT with mediastinal windows, and lack of $^{18}$F-labeled 2-deoxy-D-glucose uptake in (C) positron emission tomography/CT. Despite the negative positron emission tomography, the lesion was biopsied because of the indeterminate calcification pattern and increase in size compared with 3 years earlier (not shown). Pathology revealed dense fibrosis, focal chronic inflammation, and no malignant cells.
change in diameter may be difficult to detect. For example, a 4-mm nodule will increase to only 5 mm in diameter after doubling in volume. Additionally, it has recently been shown that significant inter- and intraobserver variability in lesion measurement, particularly in lesions with spiculated margins, are confounding factors in determining growth.\textsuperscript{53,54} It has been suggested that, for evaluating nodule size and growth, the measurement of volume is a more accurate and reproducible than the measurement of diameters, and that automated volume techniques are potentially useful for assessing growth.\textsuperscript{55,56}

### Nodule Enhancement and Metabolism

There are qualitative and quantitative differences in nodule perfusion and metabolism when comparing benign and malignant lesions.

Contrast-enhanced CT has been shown in a multi-institutional trial to be useful in determining the likelihood of malignancy of nodules between 5 mm and 3 cm.\textsuperscript{57} The intensity of nodule enhancement is directly related to the vascularity of the nodule, which is increased in malignant lesions.\textsuperscript{57-59} Malignant lesions greater than 3 cm may show necrosis and fail to enhance, leading to a false-negative study. In the CT-enhancement protocol, 3-mm collimation images of the nodule are obtained before and after the intravenous administration of contrast (2 mL/s; 300-mg iodine/mL; 420-mg iodine/kg of body weight). Serial 5-second spiral acquisitions (3-mm collimation scans with 2-mm reconstruction intervals; 120 kVp, 280 mA, pitch of 1:1; standard reconstruction algorithm; 15-cm field of view) are performed at 1,
2, 3, and 4 minutes after the onset of contrast injection. Enhancement is determined by subtracting the precontrast attenuation of the nodule from the peak nodule attenuation after contrast administration. To obtain measurements, the circular or oval region of interest is centered on the image closest to the nodule equator and should comprise roughly 70% of the diameter of a nodule. Region-of-interest measurements should be made on mediastinal window settings to minimize partial volume averaging. Careful inspection of the adjacent bronchovascular bundles to obtain region-of-interest measurements of the nodule at similar levels in the z-axis on serial scans is recommended. Typically, malignant nodules enhance more than 20 Hounsfield units (HU), while benign nodules enhance less than 15 HU. When a cutoff of 15 HU is used, the negative predictive value for malignancy is 96%. There are, however, several potential limitations to clinical application of this technique. This technique should only be performed on nodules greater than 5 mm, relatively spherical in shape, and relatively homogeneous in attenuation (ie, without evidence of fat, calcification, cavitation, or necrosis). Because nodules that enhance less than 15 HU are almost certainly benign (sensitivity 98%, specificity 58%, accuracy 77%), the clinical utility of this technique, despite its limitations, does enable conservative management with serial imaging reassessment.

Recently, computer-aided diagnosis has been used to assist in differentiating benign from malignant nodules by examining vascular enhancement and nodule morphology. In a study by Shah and Truong et al.,
colleagues\textsuperscript{60} a computer-aided diagnosis system used quantitative features to describe the nodule’s size, shape, attenuation, and enhancement properties to differentiate benign from malignant nodules. This study showed that computer-aided diagnosis using volumetric and contrast-enhanced data from 35 CT data sets of solitary pulmonary nodules with a mean diameter of 25 mm (range 6–54 mm) is useful in assisting in the differentiation of benign and malignant solitary pulmonary opacities.

An alternative to CT enhancement to differentiate benign from malignant pulmonary nodules is functional imaging using 18F-labeled 2-deoxy-D-glucose (FDG) positron emission tomography (PET). The most common semiquantitative method of evaluation of pulmonary lesions using PET is FDG standardized uptake value (SUV\textsubscript{max}). Metabolism of glucose is typically increased in malignancies and an SUV\textsubscript{max} cutoff of 2.5 has been used to differentiate benign from malignant nodules.\textsuperscript{61} PET has a sensitivity and specificity of approximately 90\% for detection of malignancy in nodules 10 mm or greater in diameter.\textsuperscript{62} To properly tailor patient management, FDG PET evaluations of solitary pulmonary nodules must be considered alongside such clinical risk factors as patient age, smoking history, and history of malignancy (Fig. 14). For instance, in a patient with a low pretest likelihood of malignancy (20\%) being considered for serial imaging reassessment, a negative PET will reduce the likelihood of

![Fig. 12. Sixty-seven-year-old man with emphysema. (A) Contrast-enhanced CT shows a spiculated right apical lesion (arrow) has increased in size compared with (B) contrast-enhanced CT of 8 months earlier showing same lesion (arrow). Biopsy revealed a neuroendocrine carcinoma. Note that nodule growth is an important consideration when assessing lesions for malignant potential.](image)

![Fig. 13. Fifty-eight-year-old man with a pulmonary metastasis from a nasopharyngeal cancer. (A) Contrast-enhanced CT shows a small, well-circumscribed right upper lobe nodule. (B) Contrast-enhanced CT performed 28 days later shows a marked increase in size of right upper lobe lesion. Note that, although volume-doubling time of less than 30 days suggests infection, this can also be seen in lymphoma and rapidly growing metastases.](image)
malignancy to 1% and argues for conservative management.\textsuperscript{62,63} However, in a patient with a high pretest likelihood of malignancy (80%), a negative PET will only reduce the likelihood of malignancy to 14%.\textsuperscript{63,64} Accordingly, obtaining tissue for diagnosis with biopsy or resection would be recommended.

The high sensitivity and specificity of PET in the evaluation of solitary pulmonary nodules pertain to solid nodules of 10 mm or greater in diameter. However, FDG-uptake in malignant ground-glass and partly solid nodules is variable and cannot be used to differentiate benign from malignant lesions. In a recent study, 9 of 10 well-differentiated adenocarcinomas presenting as ground-glass nodular opacities were falsely negative on PET while 4 of 5 benign ground-glass nodular opacities were falsely positive.\textsuperscript{55} The sensitivity (10%) and specificity (20%) for ground-glass opacities in this study were significantly lower than that for solid nodules (90% and 71%, respectively). Limitations in spatial resolution can also result in false-negative studies when lesions smaller than 10 mm in diameter are evaluated.\textsuperscript{65,66} With advances in PET technology, the evaluation of nodules of approximately 7 mm is possible.\textsuperscript{57} Otherwise, false-negative PET results are uncommon, but may occur with carcinoid tumors and bronchioloalveolar carcinomas (Fig. 15).\textsuperscript{68–70} The lower positive predictive value relates to the false-positive lesions due to infection and inflammation (Fig. 16).

The recent introduction of integrated PET/CT scanners has introduced the near-simultaneous acquisition of coregistered, spatially matched functional and anatomic data. The temporal and spatial fusion of these two data sets can be useful when used as the initial imaging modality in solitary pulmonary opacity characterization.\textsuperscript{71} In a study comparing PET/CT and helical dynamic CT in the evaluation of solitary pulmonary nodules, PET/CT was more sensitive (96% vs. 81%) and accurate (93% vs. 85%) than helical dynamic CT.\textsuperscript{71} However, the use of CT for attenuation correction of the PET images has introduced artifacts and quantitative errors that can affect the emission image and lead to misinterpretation.\textsuperscript{72} For instance, imaging during different stages of

\textbf{Fig. 14.} Seventy-seven-year-old woman with emphysema and a history of smoking 3 packs of cigarettes per day for 40 years. (A) Contrast-enhanced CT with lung windows, (B) contrast-enhanced CT with mediastinal windows, and (C) PET/CT show a hypometabolic, spiculated left apical lung nodule with eccentric calcification (arrow). Despite the negative PET, further evaluation (biopsy or resection) is required because of the high clinical suspicion of malignancy owing to the age of the patient, smoking history, emphysema, and nodule characteristics of spiculation and eccentric calcification.
the patient’s respiratory cycle may introduce a mismatch between the CT attenuation data obtained during breath-hold and the PET emission data obtained during quiet tidal breathing. In addition to localization errors, this misregistration may also result in incorrect attenuation coefficients applied to the PET data that can affect the SUVmax, the most widely used parameter to quantify the intensity of FDG uptake. Misregistration may lead to SUVmax being lower than expected and can potentially result in a false-negative study. Strategies to reduce the respiratory mismatch between the CT and PET images include obtaining the CT scan at end expiration, which most closely approximates the lung volumes during PET data acquisition at quiet tidal breathing. However, CT of the lungs at end expiration compromises anatomic detail and small nodules may be obscured. A more recent approach suggests the use of respiratory-averaged CT (CT cine images obtained over different portions of the respiratory cycle using four-dimensional CT techniques) to improve SUVmax quantification. Respiratory-averaged CT used for attenuation correction of a PET scan has shown SUVmax differences of more than 50% in some lesions as compared with the standard method of CT attenuation using data obtained in the mid-expiratory phase.

**DECISION ANALYSIS**

Management algorithms for solitary pulmonary nodules are determined by patients’ clinical risk.

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**Fig. 15.** Sixty-two-year-old woman with endometrial cancer and a right lung nodule detected on a preoperative chest radiograph. (A) Contrast-enhanced CT and (B) PET/CT show well-circumscribed hypometabolic nodule (arrow) in the right lower lobe. Transthoracic needle biopsy revealed a well-differentiated neuroendocrine tumor. Note that false-negative PET results may be seen with carcinoid and bronchioalveolar carcinoma.

**Fig. 16.** Seventy-seven-year-old man with an esophageal cancer treated with chemoradiation. (A) CT and (B) PET/CT show a new well-circumscribed hypermetabolic left lower lobe nodule (arrow in A) with SUVmax of 9.3 suspicious for a metastasis. Asterisk in B shows esophageal cancer. Transthoracic needle aspiration biopsy revealed no malignant cells. Fungal elements morphologically consistent with Cryptococcus were identified. Note that infectious and inflammatory conditions with increased glucose metabolism can accumulate FDG and be misinterpreted as malignant.
factors as well as nodule characterization. Benign nodules, either because of their pattern of calcification or their stability over a long time, require no further evaluation. Nodules determined to be benign because of their pattern of calcification or their stability over a long time require no further evaluation. However, many nodules remain indeterminate in etiology after comprehensive noninvasive radiologic assessment. At this juncture in decision analysis, management options include observation with imaging reassessment, biopsy, or resection of the nodule. Detection of pulmonary nodules has increased with MDCT and many of these lesions are small (<7 mm) and benign. Multiple factors, including radiation exposure, cost, limited resources, patient anxiety, and the knowledge gleaned from the lung cancer CT screening trials have contributed to the recent release of guidelines for the management of pulmonary nodules discovered incidentally on routine and screening CT by the Fleischner Society and more recently by the American College of Chest Physicians. These guidelines take into consideration lesion size, morphology, and growth rate and patient age and smoking history. In terms of size, small nodules (<4 mm) have a less than 1% chance of being a primary lung cancer, even in people who smoke, while the risk of malignancy increases to 10% to 20% in nodules in the 8-mm range.

**FLEISCHNER SOCIETY RECOMMENDATIONS**

The following list gives the Fleischner Society’s recommendations for an incidentally discovered nodule in an adult patient:

**A. Low-risk populations (little or no history of smoking, and no other risk factors)**
1. Nodule equal to or smaller than 4 mm: likelihood of malignancy very small and no reassessment is necessary.
2. Nodule greater than 4 mm but less than or equal to 6 mm: reassessment CT at 12 months and, if stable, no further evaluation is required. The exception is the non-solid or partly solid nodule, which may need to be reassessed to exclude the risk of an indolent adenocarcinoma.
3. Nodule greater than 6 mm but less than or equal to 8 mm: reassessment CT at 6 to 12 months and, if stable, again at 18 to 24 months.
4. Nodule greater than 8 mm: either reassessment CT scans at 3, 9, and 24 months to assess for stability in size or further evaluation with contrast-enhanced CT, PET/CT, or biopsy or resection.

**B. High-risk populations (history of smoking, or other exposure or risk factor)**
1. Nodule equal to or smaller than 4 mm: reassessment at 12 months and, if stable, no further evaluation is required. The exception is the non-solid or partly solid nodule, which may need to be reassessed to exclude the risk of an indolent adenocarcinoma.
2. Nodule greater than 4 mm but less than or equal to 6 mm: Reassessment CT at 6 to 12 months and, if stable, again at 18 to 24 months.
3. Nodule greater than 6 mm but less than or equal to 8 mm: reassessment CT at 3 to 6 months and, if stable, again at 9 to 12 months and at 24 months.
4. Nodule greater than 8 mm: either reassessment CT at 3, 9, and 24 months to assess stability or perform contrast-enhanced CT, PET/CT, or biopsy or resection.

The Fleischner recommendations do not apply to patients with a history of malignancy, patients under 35 years with low risk of lung cancer, and in those patients with fever in which the nodules may be infectious. For nodule reassessment, a non-contrast, thin-collimation, limited-coverage, low-dose CT scan is recommended by the Fleischner Society. An example of a low-dose protocol is a 120-kilovolt (peak), 40–50-mAs algorithm reconstructed at 2.5 mm slice thickness with 2-mm intervals.

**SUMMARY**

With the increasing use of MDCT, more solitary pulmonary nodules are being detected. Although the majority of these lesions are benign, lung cancer constitutes an important consideration in the differential diagnosis of solitary pulmonary nodules. The goal of management is to correctly differentiate malignant from benign nodules to ensure appropriate treatment. Stratifying patients’ risk factors for malignancy, including patient age, smoking history, and history of malignancy, is essential in the management of solitary pulmonary nodules. In terms of radiologic evaluation, obtaining prior films is important to assess for nodule growth. The detection of certain patterns of calcification and stability for 2 years or more have historically been the only useful findings for determining whether a nodule is or is not benign. However, recent technological advances in imaging, including MDCT and PET/CT, have improved nodule characterization and surveillance. For solid
nodules, CT enhancement of less than 15 HU and hypometabolism on PET (SUV\text{max} <2.5) favor a benign etiology. Potential pitfalls in nodule enhancement and PET evaluation of solitary pulmonary nodules include infectious and inflammatory conditions. Stratified according to patient risk factors for malignancy and nodule size, recent guidelines for the management of incidentally detected small pulmonary nodules have been useful in decision analysis. An important exception to these guidelines is the evaluation and management of the subsolid nodule. These lesions are not suitable for CT enhancement studies and may show low metabolic activity on PET imaging. Due to their association with bronchioloalveolar carcinoma and adenocarcinoma, subsolid nodules require a more aggressive approach in terms of reassessing serial imaging and/or obtaining tissue diagnosis. As data from the low-dose CT lung cancer screening trials are analyzed and further studies with new imaging techniques are performed, management strategies for the imaging evaluation of the solitary pulmonary nodule will continue to evolve.

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