CT MORPHOLOGIC PATTERNS OF PRIMARY LUNG CANCER: A PICTORIAL REVIEW

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Abstract: Primary lung cancer remains the leading cause of cancer-related mortality worldwide. Computed tomography (CT) plays a central role in its early detection, morphologic assessment, and staging. While histological confirmation is essential, CT findings often provide critical insights into tumor subtype, invasiveness, and potential treatment pathways. This pictorial review systematically presents the CT morphologic patterns associated with primary lung cancers, focusing on solid nodules, ground-glass opacities, cavitary lesions, endobronchial tumors, and consolidative opacities. Radiologic-pathologic correlations are emphasized, with interpretive strategies to distinguish malignant lesions from common mimickers. Understanding these morphologies supports accurate diagnosis, optimal biopsy targeting, and multidisciplinary treatment planning.
Keywords: lung cancer, computed tomography, morphologic patterns, adenocarcinoma, squamous cell carcinoma, small cell carcinoma, radiologic-pathologic correlation

1. INTRODUCTION

Primary lung cancer remains the leading cause of cancer-related mortality worldwide, exceeding breast, colorectal, and prostate cancers combined (Rami-Porta et al., 2024; Rampinelli et al., 2016). Most patients present at advanced stages due to an often-silent clinical course, underscoring the pivotal role of imaging in early detection and accurate tumor characterization (Travis et al., 2015; Viohl et al., 2025). Computed tomography (CT), particularly multidetector CT (MDCT), enables high-resolution assessment of pulmonary lesions, providing detailed information on tumor size, morphology, and local extension (Li et al., 2025; Kuhtić et al., 2015).
Characteristic CT features—including spiculation, lobulation, ground-glass components, and cavitation—aid in distinguishing malignant from benign entities and can suggest histologic subtypes in selected cases (Takeo et al., 2012; Kuhtić et al., 2015). The recognition of spread through air spaces (STAS) has strengthened radiologic–pathologic correlation in adenocarcinomas, linking it to aggressive behavior and worse prognosis (Zhang et al., 2024; Travis et al., 2025).
Low-dose CT (LDCT) screening, as demonstrated in the National Lung Screening Trial (NLST), reduces lung cancer mortality in high-risk groups by facilitating detection at potentially curable stages (National Lung Screening Trial Research Team, 2011). Nonetheless, interpretation challenges remain, particularly in differentiating malignancies from benign mimics and managing atypical imaging presentations within non-contrast screening protocols (Callister et al., 2015). A systematic understanding of CT morphologic patterns, integrated with clinical and histopathologic correlation, is therefore essential for timely diagnosis, accurate staging, and multidisciplinary treatment planning.

2. IMAGING PROTOCOL AND TECHNIQUE

High-quality thoracic CT imaging is fundamental for the detection, characterization, and staging of primary lung cancer. A standardized lung cancer protocol typically includes both non-contrast and contrast-enhanced chest CT acquisitions, performed with thin slices (≤1.25 mm collimation) on multidetector CT scanners during full inspiration. Such technical precision ensures optimal spatial resolution, accurate assessment of pulmonary nodules, and reproducible follow-up comparisons.
Contrast Use. Intravenous iodinated contrast is strongly recommended for staging, as it improves visualization of mediastinal lymphadenopathy, chest wall or pleural invasion, and vascular encasement or thrombosis. Contrast-enhanced imaging therefore plays a crucial role in determining resectability and guiding multidisciplinary treatment decisions.
Image Reconstruction. Multiplanar reconstructions in axial, coronal, and sagittal orientations are essential to evaluate lesion morphology, broncho-vascular relationships, and invasion of adjacent structures. Lung windows (width ~1500 HU, level ~–600 HU) allow detailed analysis of parenchymal nodules, ground-glass opacities (GGOs), and cavitary changes, while mediastinal windows (width ~400 HU, level ~40 HU) enhance the assessment of lymph nodes, vasculature, and soft tissue extension.
Advanced Visualization Tools.

- *Minimum Intensity Projection (MinIP)* highlights subtle ground-glass abnormalities and airspace opacities, useful for detecting early adenocarcinomas or mucinous tumors.

- *Maximum Intensity Projection (MIP)* improves the detection of small pulmonary nodules and emphasizes vascular convergence; an imaging feature often associated with malignancy.

Interpretive Strategy. A structured, systematic evaluation should address:

- **Lesion location:** central versus peripheral distribution
- **Size and margins:** presence of spiculation, lobulation, or smooth contour
- **Internal composition:** solid, part-solid, ground-glass, or cavitary morphology
- **Ancillary signs:** air bronchograms, pleural retraction, vessel convergence, or encasement

Adhering to a consistent imaging protocol not only improves lesion detectability and diagnostic confidence but also optimizes morphologic subtype characterization, ensuring accuracy in longitudinal follow-up and multidisciplinary treatment planning.

3. CT MORPHOLOGIC PATTERNS OF PRIMARY LUNG CANCER

Primary lung cancers display a wide spectrum of CT morphologies that correlate with histologic subtype, tumor growth pattern, and underlying biological behavior. Recognition of these morphologic features is crucial not only for diagnosis but also for predicting invasiveness, guiding biopsy site selection, and informing therapeutic planning (Furuya et al., 2024; Zhang et al., 2024). Contemporary studies have identified five dominant morphologic patterns that are most frequently encountered in clinical practice, each with characteristic CT features, histologic associations, and potential pitfalls (Li et al., 2025; Rampinelli et al., 2016).

3.1 Solid Nodules or Masses

Description

Solid nodules or masses remain the most frequent CT presentation of primary lung cancer, accounting for the majority of clinically detected cases. These lesions are visualized as well-defined or irregular soft-tissue opacities that may be located peripherally in the lung parenchyma or centrally in relation to bronchi and hilar structures, ***Figure 1***. Their morphology—size, contour, and internal characteristics—reflects both the histologic subtype and stage of disease progression. The recognition of subtle margin features and associated parenchymal changes is crucial for differentiating malignant tumors from benign mimics.

CT Features

- **Margins**: Spiculated or lobulated contours are highly suggestive of malignancy, reflecting desmoplastic stromal reaction.
- **Pleural Interaction**: Indentation, retraction, or tethering of adjacent pleura commonly indicates an invasive process.
- **Internal Characteristics**: Central necrosis and heterogeneous enhancement are frequent in larger or rapidly growing masses.
- **Bronchial Pattern**: Air bronchograms may be seen, particularly in adenocarcinomas with preserved alveolar structures.

Histologic Correlation

- **Squamous cell carcinoma** often presents as a centrally located bulky mass, frequently associated with smoking, and may lead to endobronchial obstruction (Kuhtić et al., 2015).
- **Large cell carcinoma** typically manifests as a large, rapidly enlarging peripheral lesion, often demonstrating central necrosis.
- **Adenocarcinoma** may present as a solitary solid nodule in its invasive stage, particularly in non-smokers and peripheral lung locations.

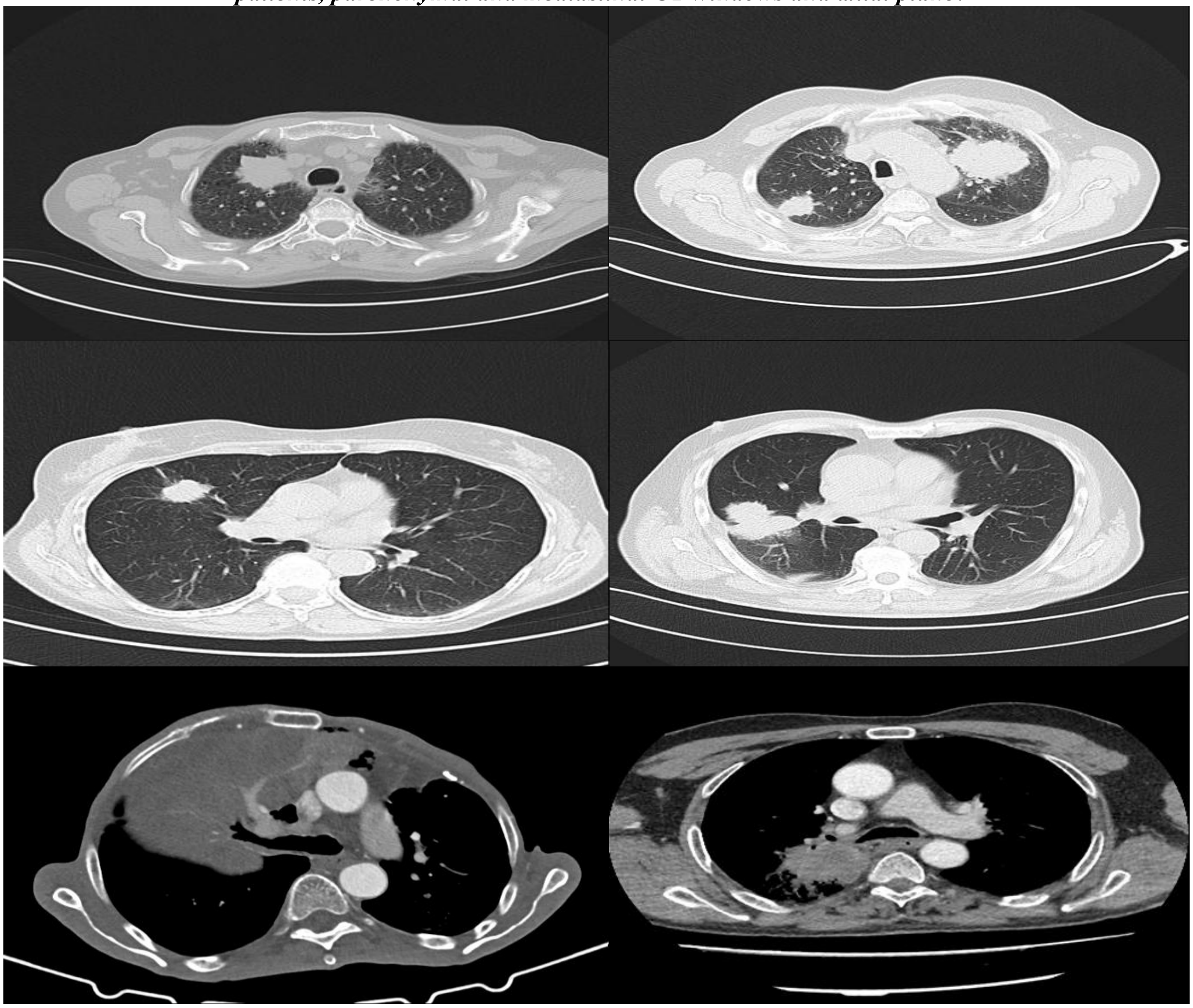
Pitfalls

Several benign and infectious processes may mimic solid cancer morphology. Granulomatous infections (e.g., tuberculosis, histoplasmosis) can produce irregular, spiculated nodules with central necrosis. Round atelectasis may create a pseudotumoral appearance, while inflammatory nodules or organizing pneumonia may present as solitary soft-tissue opacities. These mimics highlight the necessity of correlation with clinical history, serial imaging, and tissue sampling when features remain indeterminate.

Clinical Note

The presence of **satellite nodules, vascular convergence, fissural distortion, and associated lymphadenopathy** significantly heightens the probability of malignancy (Viohl et al., 2025). Radiologists should report these ancillary signs explicitly, as they influence staging, biopsy targeting, and multidisciplinary management decisions.

Figure 1. CT Appearances of Solid Pulmonary Nodules and Masses in Primary Lung Cancer in different patients, parenchymal and mediastinal CT windows and axial plane.



Source: Author

3.2 Ground-Glass Nodules (GGNs)

Description

Ground-glass nodules (GGNs) are hazy areas of increased attenuation that preserve underlying bronchovascular architecture. They may present as **pure (non-solid) GGNs** or **part-solid GGNs**, each carrying distinct diagnostic and prognostic significance, ***Figure 2***. On CT, pure GGNs frequently correspond to pre-invasive adenocarcinoma spectrum lesions, while part-solid nodules are highly predictive of invasive disease. Recognition of these patterns is essential, as they directly impact surveillance strategies, biopsy decisions, and surgical planning.

CT Features

- **Pure GGNs**: Indolent in behavior, often representing atypical adenomatous hyperplasia (AAH) or adenocarcinoma in situ (AIS). They demonstrate stability or minimal interval growth over long periods.
- **Part-solid GGNs**: Contain a measurable solid component, which strongly correlates with invasive adenocarcinoma. These lesions demonstrate higher malignant potential than pure GGNs.
- **Ancillary Signs**: Bubble-like lucencies, fine internal septations, air bronchograms, and vascular convergence toward the lesion are highly suspicious for malignancy and provide additional morphologic clues.

Histologic Correlation

Pure GGNs most often correspond to pre-invasive lesions such as AAH or AIS. In contrast, part-solid lesions frequently represent **minimally invasive adenocarcinoma (MIA)** or **invasive adenocarcinoma with lepidic**

growth (Li et al., 2025). The degree of the solid component is a strong predictor of tumor invasiveness, prognosis, and potential for nodal spread.

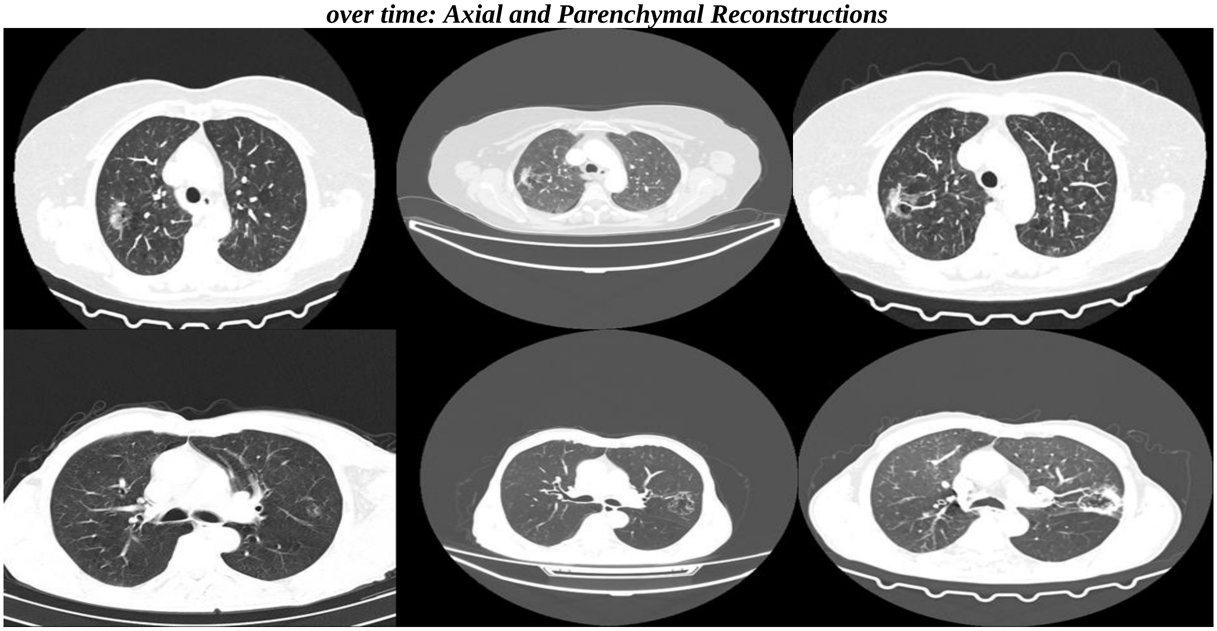
Pitfalls

GGNs are not pathognomonic for malignancy. Transient GGNs can occur secondary to infection, hemorrhage, or inflammatory conditions such as organizing pneumonia. Rampinelli et al. (2016) emphasized the importance of **short-interval follow-up (e.g., 3 months)** to confirm persistence before labeling lesions as neoplastic.

Clinical Note

Part-solid GGNs carry the **highest malignant risk** among subsolid nodules. Progressive increase in size or solid component mandates surgical consideration. Radiologists should highlight these findings in reports, as early intervention significantly improves survival outcomes. For pure GGNs, long-term imaging surveillance remains appropriate, given their slower natural history.

Figure 2. CT Representation of Part-Solid Ground-Glass Nodules in two different patients and their progression over time: Axial and Parenchymal Reconstructions



Source: Author

3.3 Cavitary Lesions

Description

Cavitary pulmonary lesions represent an important morphologic subset of lung cancers, most often arising from central necrosis and parenchymal destruction, ***Figure 3***. They are particularly frequent in **squamous cell carcinoma**, which has a propensity for rapid growth, central cavitation, and airway involvement. Less commonly, cavitation may be observed in poorly differentiated adenocarcinoma or large cell carcinoma. Recognition of this pattern is critical, as cavitating tumors are often aggressive and associated with advanced disease at presentation.

CT Features

- **Wall Thickness:** Malignant cavities typically demonstrate **thickened walls (>15 mm)** compared with benign counterparts.
- **Margin Characteristics:** Irregular or nodular inner margins, sometimes with polypoid projections.
- **Content:** Air-fluid levels may occur due to superimposed infection or necrotic debris.
- **Associated Findings:** Adjacent consolidation, satellite nodules, and signs of bronchovascular invasion may be present.

Histologic Correlation

- **Squamous Cell Carcinoma:** The most common histology to cavitate, often located in central lung regions in smokers (Kuhtić et al., 2015).
- **Adenocarcinoma (poorly differentiated):** Cavitation occurs less frequently, often in aggressive subtypes.
- **Large Cell Carcinoma:** Can present as cavitating peripheral masses with rapid progression.

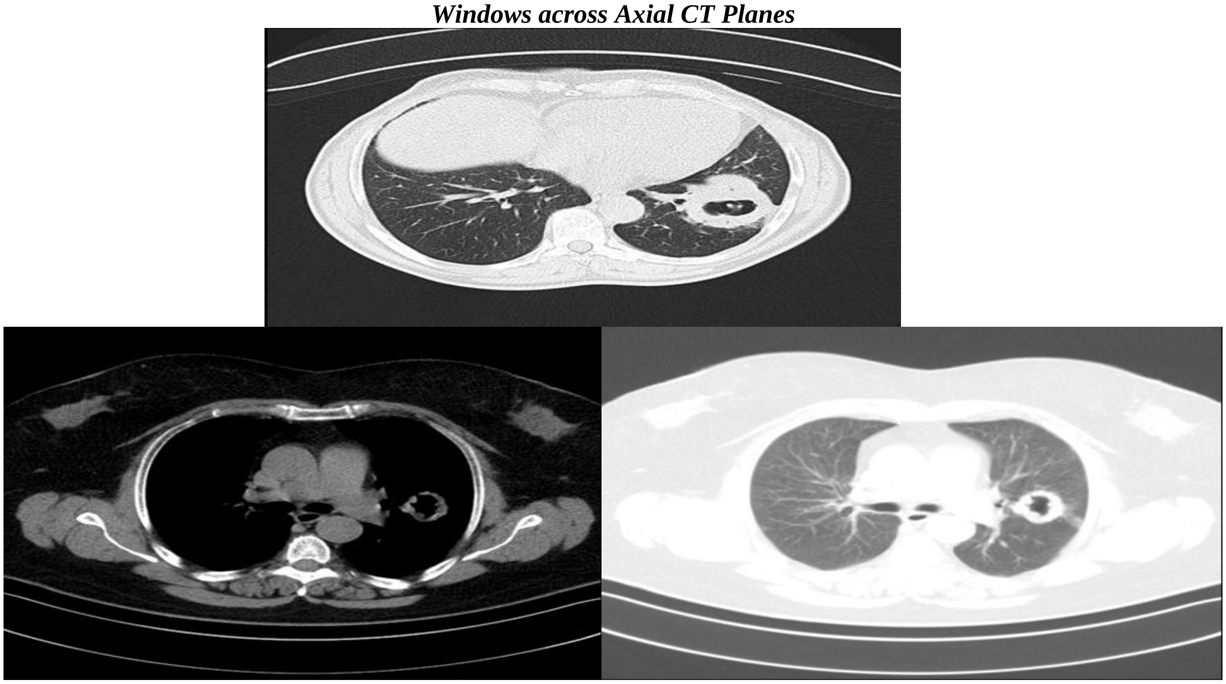
Pitfalls

Several infectious and non-neoplastic entities can mimic cavitating cancers, including **pulmonary abscesses**, **fungal infections**, and **tuberculosis**. Unlike malignancy, benign cavities typically demonstrate thinner walls (<4 mm) and smoother inner margins. Serial imaging and clinical correlation—particularly the presence of progressive growth, persistent wall irregularity, and associated lymphadenopathy—favor malignancy over benign mimics.

Clinical Note

Cavitating lung cancers are frequently associated with **hemoptysis**, post-obstructive infections, and **necrotic mediastinal lymphadenopathy**. These features are considered markers of aggressive biology and correlate with a **poorer prognosis** (Zhang et al., 2024). Multiplanar reconstructions and contrast-enhanced CT are particularly valuable to assess the extent of parenchymal destruction, vascular encasement, and nodal necrosis, all of which guide biopsy planning and therapeutic strategy.

Figure 3. CT Depiction of Cavitating Lung Carcinomas in two different patients: Parenchymal and Mediastinal Windows across Axial CT Planes



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3.4 Endobronchial Tumors

Description

Tumors originating within the bronchial lumen represent an important subset of primary lung cancers, often leading to **airway obstruction** and subsequent secondary pulmonary changes. These lesions may be central in location and cause clinical symptoms such as cough, recurrent pneumonia, or hemoptysis, ***Figure 4***. Recognition of endobronchial growth on CT is vital for timely diagnosis, as airway obstruction may mimic infectious or inflammatory disease.

CT Features

- **Intraluminal Mass:** Soft-tissue attenuation partially or completely occluding the bronchial lumen.
- **Post-Obstructive Changes:** Atelectasis, segmental or lobar consolidation, and, in some cases, compensatory hyperinflation distal to the obstruction.
- **Airway Morphology:** Abrupt cutoff, focal bronchial narrowing, or localized dilatation proximal to the mass.
- **Calcification:** Occasionally present, particularly in **typical carcinoid tumors**, which tend to enhance strongly due to vascularity.

Histologic Correlation

- **Squamous Cell Carcinoma:** The most frequent central endobronchial malignancy, typically in heavy smokers.

- **Small Cell Carcinoma:** Commonly central, often associated with bulky hilar or mediastinal lymphadenopathy and early metastatic spread.
- **Carcinoid Tumors:** Typically arise in younger patients, with slow growth, high vascularity, and frequent endobronchial location. (Furuya et al., 2024).

Pitfalls

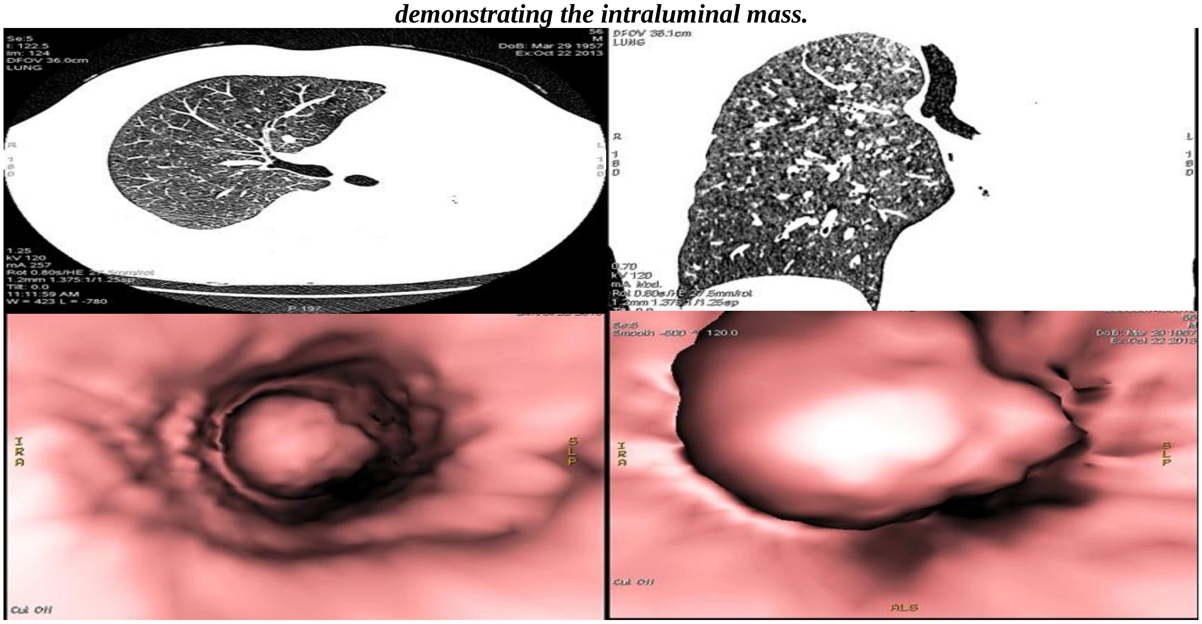
Endobronchial tumors may be mimicked by several benign entities:

- **Mucus plugging**, which can appear as an intraluminal filling defect but typically has lower attenuation and resolves with follow-up.
- **Foreign body aspiration**, more common in younger patients, often associated with localized obstructive changes.
- **Endobronchial infection**, which can cause transient airway obstruction.
  Adjunctive modalities such as **PET/CT** and **bronchoscopy** play a key role in differentiating malignant lesions from benign mimics.

Clinical Note

A strong red flag is **recurrent post-obstructive pneumonia** affecting the same lobe or segment, which should prompt evaluation for an endobronchial neoplasm. Early detection is critical, as surgical resection or bronchoscopic therapy can be curative in localized carcinoids, while aggressive malignancies such as small cell carcinoma require immediate staging and systemic therapy.

Figure 4. Endobronchial tumor of the left bronchus resulting in complete luminal obstruction. Shown on axial and coronal parenchymal CT reconstructions, with additional virtual bronchoscopy depiction directly demonstrating the intraluminal mass.



Source: Author

3.5 Consolidative Opacities

Description

A subset of primary lung cancers presents as consolidative opacities, often resembling infectious pneumonia. These lesions typically appear as homogeneous or patchy areas of increased attenuation that maintain underlying bronchial and vascular structures, a feature that may initially mislead clinicians. Because of this, they are sometimes termed "pneumonic-type" lung cancers. ***Figure 5*** illustrates this morphologic presentation.

CT Features

- Persistent air bronchograms within the consolidated region
- Lack of response to antibiotic therapy or persistence beyond expected resolution
- Multifocal, lobar, or segmental distribution that does not follow typical infectious patterns
- Frequently associated with ground-glass components, pseudocavitations, or a "crazy-paving" pattern

Histologic Correlation

Invasive mucinous adenocarcinoma represents the classic histology associated with this consolidative morphology. The tumor's abundant mucin production leads to widespread filling of alveolar spaces, producing CT appearances that mimic pneumonia. Unlike infection, however, these consolidations often demonstrate migration or extension to new areas over time (Furuya et al., 2024; Travis et al., 2024).

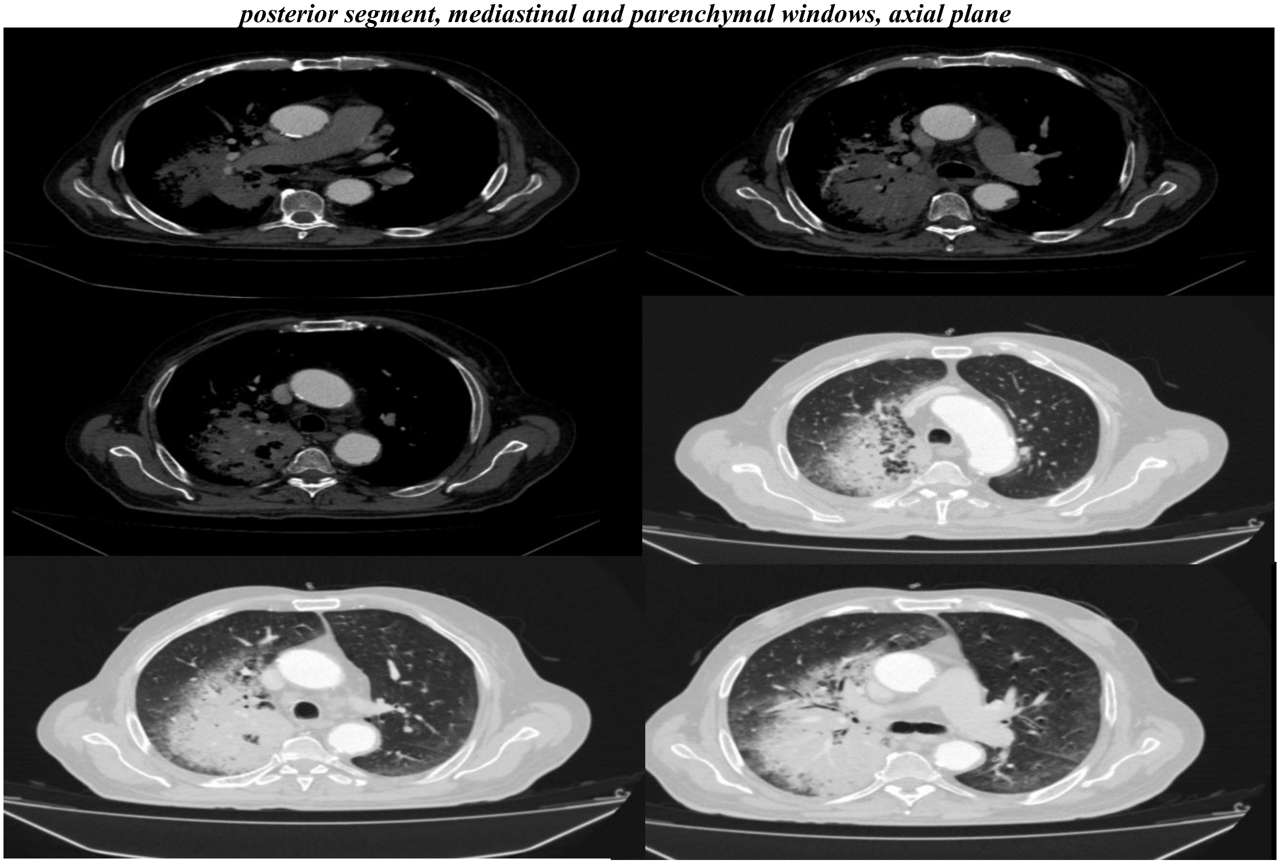
Pitfalls

Several benign processes can closely resemble this morphologic pattern. Cryptogenic organizing pneumonia, eosinophilic pneumonia, and alveolar hemorrhage are common differential considerations. Clinical and temporal evaluation are crucial—resolution or regression with therapy favors benign etiologies, whereas progressive or migratory opacities despite treatment strongly suggest malignancy.

Clinical Note

Radiologists should maintain a high index of suspicion when confronted with non-resolving or migratory consolidations, particularly in patients without systemic signs of infection. Early consideration of invasive mucinous adenocarcinoma is essential, and prompt biopsy is recommended to avoid delays in diagnosis and management.

Figure 5. Consolidative Morphology of Invasive Mucinous Adenocarcinoma Mimicking Pneumonia on CT, URL, posterior segment, mediastinal and parenchymal windows, axial plane



Source: Author

5. PATTERNS SUGGESTING SPECIFIC HISTOLOGIC SUBTYPES

While histopathologic confirmation remains the diagnostic gold standard, certain CT morphologic patterns can suggest the likely histologic subtype before biopsy, aiding in prioritization of diagnostic workup and guiding clinical urgency (Furuya et al., 2024; Li et al., 2025). ***Table 1*** summarizes characteristic CT appearances and their most common histologic associations.

Table 1. CT morphologic features suggestive of specific histologic subtypes

Histologic Type	Typical CT Appearance
Adenocarcinoma	Peripheral lesion with spiculation, part-solid morphology, pleural retraction; occasional ground-glass areas
Minimally Invasive / AIS	Pure GGNs with slow growth, bubble lucencies, and vessel convergence
Squamous Cell Carcinoma	Central solid or cavitary mass with lobulated margins; frequent endobronchial extension
Small Cell Carcinoma	Central, bulky mass with mediastinal lymphadenopathy, vascular encasement, and rapid growth
Large Cell Carcinoma	Large peripheral solid mass, often necrotic; aggressive progression
Mucinous Adenocarcinoma	Consolidative opacities with air bronchograms; multifocal or migratory distribution
Carcinoid Tumor	Central, well-defined, enhancing mass; possible calcification; slow-growing endobronchial lesion

Source: Author

Clinical Note: Imaging alone cannot definitively establish histologic subtype, but recognition of these patterns can refine the differential diagnosis. For example, small cell carcinoma demands urgent staging and initiation of therapy due to its aggressive nature, whereas pure GGNs typically warrant prolonged surveillance with low-dose CT (Zhang et al., 2024).

6. CT DIFFERENTIAL DIAGNOSIS: MIMICKERS AND PITFALLS

Although many CT features are strongly suggestive of malignancy, a variety of benign and inflammatory conditions can mimic primary lung cancer. Failure to recognize these entities can lead to unnecessary biopsies or delays in appropriate therapy (Viohl et al., 2025), ***Table 2***.

Table 2. Benign Neoplasms and Inflammatory Mimics

Entity	Key CT Features
Granulomas (e.g., TB, histoplasmosis)	Dense or central calcification; stability over years; may have satellite nodules
Organizing Pneumonia	Patchy consolidation with air bronchograms; migratory course; rapid steroid response
Pulmonary Abscess	Thick-walled cavity with fluid levels; surrounding consolidation; systemic infection signs
Hamartoma	Well-circumscribed nodule containing fat attenuation or “popcorn” calcification
Round Atelectasis	Comet-tail sign; pleural contact and volume loss; associated pleural thickening
Lipoid Pneumonia	Low attenuation within consolidation; history of aspiration; slow resolution
Fungal Infections	Halo sign or reverse-halo sign; common in immunocompromised patients

Source: Author

6.2 Diagnostic Strategies to Differentiate

- Temporal Evolution: Malignancies tend to grow over weeks to months; benign lesions are often stable or regress over time.
- Enhancement Pattern: Irregular or heterogeneous enhancement supports malignancy; absence or uniform enhancement suggests benign etiology.
- Ancillary Signs: Features such as pleural retraction, vascular convergence, and lymphadenopathy favor malignancy.
- Clinical Context: History of smoking, weight loss, hemoptysis, or occupational exposure should heighten suspicion (Furuya et al., 2024).

Effective differentiation requires integrating morphologic patterns with clinical data and, where necessary, functional imaging such as PET/CT or histologic sampling.

7. PRACTICAL DIAGNOSTIC PEARLS FOR RADIOLOGISTS

To optimize diagnostic accuracy and ensure consistency in CT interpretation for suspected lung cancer, the following strategies are recommended (Li et al., 2025; Viohl et al., 2025):

- Evaluate all lesions in both lung and mediastinal windows to assess parenchymal details, soft tissue invasion, and lymphadenopathy.
- Compare with prior imaging to detect growth or morphological change—one of the most reliable indicators of malignancy.
- Identify subtle high-risk signs such as spiculation, pleural tags, bubble lucencies, and vessel convergence.
- Apply structured reporting systems such as Lung-RADS or Fleischner Society recommendations to standardize follow-up and management.
- Incorporate clinical context, including smoking history, occupational exposures, prior malignancy, and immunosuppression status.
- Communicate urgent or suspicious findings promptly to the multidisciplinary team to facilitate timely biopsy, staging, and treatment planning.

Integrating morphologic pattern recognition with clinical correlation and standardized reporting improves early cancer detection and supports personalized oncologic care.

8. CONCLUSION

CT-based morphologic analysis remains an indispensable tool in the detection, characterization, and staging of primary lung cancer. High-resolution multidetector CT enables radiologists to evaluate lesion architecture, margins, internal components, and associated findings with a degree of precision that often allows suspicion of malignancy—and even prediction of histologic subtype—before histopathologic confirmation (Furuya et al., 2024; Li et al., 2025).
Recognition of distinct morphologic patterns—including solid spiculated nodules, part-solid and pure ground-glass nodules, cavitary lesions, endobronchial masses, and consolidation-mimicking invasive mucinous adenocarcinomas—enhances diagnostic accuracy and facilitates tailored management strategies. These patterns, when interpreted alongside ancillary features such as pleural retraction, vascular convergence, and lymphadenopathy, provide critical information for tumor staging, biopsy targeting, and surgical planning (Viohl et al., 2025).
The expanding role of lung cancer screening programs has increased the number of indeterminate pulmonary nodules encountered in clinical practice, underscoring the need for a systematic, evidence-based approach to interpretation. Structured reporting systems, integration of prior imaging for growth assessment, and close multidisciplinary collaboration are essential to minimize false positives, avoid unnecessary interventions, and ensure timely treatment for aggressive disease.
As imaging volumes rise, radiologists must remain adept at distinguishing malignancy from benign mimics through a combination of morphologic pattern recognition, clinical correlation, and awareness of potential pitfalls. By consistently applying a pattern-based diagnostic framework grounded in current evidence, radiologists can play a pivotal role in early detection, accurate staging, and optimized patient outcomes in thoracic oncology.

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