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Radio-Diagnosis

CORRELATION OF IMAGING CHARACTERISTICS OF PULMONARY NODULES ON CT WITH HISTOPATHOLOGICAL FINDINGS

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ABSTRACT **Background:** Pulmonary nodules are frequently encountered on computed tomography (CT) and represent a wide spectrum of benign and malignant pathologies. Accurate characterization of these nodules is essential for early detection of malignancy and to avoid unnecessary invasive procedures. CT morphological features provide valuable clues; however, correlation with histopathology remains crucial for definitive diagnosis.**Aim:** To evaluate the correlation between CT morphological features of pulmonary nodules and histopathological findings, and to assess the diagnostic accuracy of CT in differentiating benign and malignant lesions.**Materials and Methods:** This prospective observational study was conducted in the Department of Radiodiagnosis at Chirayu Medical College & Hospital over a period of six months (November 2025 to April 2026). A total of 50 patients with pulmonary nodules detected on CT were included. CT parameters assessed included nodule size, margins, attenuation, calcification pattern, cavitation, and enhancement characteristics. Histopathological examination obtained via biopsy or surgical resection was considered the reference standard. Statistical analysis included calculation of sensitivity, specificity, predictive values, logistic regression, and receiver operating characteristic (ROC) curve analysis.**Results:** Out of 50 nodules, 30 (60%) were malignant and 20 (40%) were benign. CT features significantly associated with malignancy included spiculated margins (83.3%, $p < 0.001$), size >2 cm (73.3%, $p = 0.002$), absence of benign calcification (80%, $p = 0.01$), and heterogeneous enhancement (70%, $p = 0.003$). Multivariate analysis identified spiculated margins (OR = 10.2) and size >2 cm (OR = 5.6) as independent predictors. CT demonstrated a sensitivity of 93.3%, specificity of 85%, and overall diagnostic accuracy of 90%. ROC analysis showed excellent performance with an area under the curve (AUC) of 0.927.**Conclusion:** CT morphological features show strong correlation with histopathological diagnosis and can reliably predict malignancy in pulmonary nodules. A combined assessment of imaging features enhances diagnostic accuracy and supports effective clinical decision-making.

KEYWORDS : Pulmonary nodules; CT scan; Lung cancer; Histopathology; Diagnostic accuracy

INTRODUCTION

Pulmonary nodules are commonly detected on imaging and may represent a wide spectrum of pathological entities ranging from benign granulomas to primary lung malignancies. With the increasing use of cross-sectional imaging, particularly computed tomography (CT), the incidental detection of pulmonary nodules has significantly increased [1,2]. Accurate differentiation between benign and malignant nodules is critical, as it directly influences patient management, follow-up strategies, and prognosis.

Lung cancer remains the leading cause of cancer-related mortality worldwide, accounting for a substantial disease burden [3]. Early detection of malignant nodules is essential to improve survival outcomes. However, distinguishing malignant nodules from benign lesions based solely on clinical presentation is often difficult, necessitating reliance on imaging characteristics.

Computed tomography (CT) plays a central role in the evaluation of pulmonary nodules, providing detailed information regarding lesion morphology, density, and enhancement patterns. Various CT features have been identified as predictors of malignancy, including larger size, irregular or spiculated margins, absence of benign calcification, ground-glass opacity, and heterogeneous enhancement [4–6]. Conversely, features such as smooth margins, central or diffuse calcification, and stability over time are more suggestive of benign etiology [7].

Despite advancements in imaging, CT findings may overlap between benign and malignant lesions, leading to diagnostic uncertainty. Therefore, histopathological examination remains the gold standard for definitive diagnosis. Correlating CT morphology with histopathological findings is essential to validate imaging criteria and enhance diagnostic accuracy [8].

Several predictive models and guidelines, such as the Fleischner Society recommendations, have been developed to guide the management of pulmonary nodules based on imaging features and clinical risk factors [9]. However, variability in imaging interpretation and patient characteristics necessitates institution-specific studies to refine diagnostic approaches.

In this context, the present study aims to evaluate CT morphological features of pulmonary nodules and correlate them with histopathological findings, thereby assessing the diagnostic accuracy of CT in differentiating benign and malignant lesions.

MATERIALS AND METHODS

Study Design

Cross sectional study

Study Setting and Duration

The study was carried out in the Department of Radiodiagnosis at Chirayu Medical College & Hospital, a tertiary care teaching hospital, over a period of six months (November 2025 to April 2026).

Study Population and Sample Size

A total of 50 consecutive patients with pulmonary nodules detected on computed tomography (CT) were included in the study. Consecutive sampling was employed to minimize selection bias and ensure representativeness.

ELIGIBILITY CRITERIA

Inclusion Criteria

- Patients aged ≥18 years
- Patients with solitary or multiple pulmonary nodules detected on CT
- Patients undergoing histopathological evaluation (biopsy or surgical resection)
- Patients providing informed consent

Exclusion Criteria

- Patients with diffuse lung disease or extensive pulmonary involvement
- Patients with previously diagnosed or treated lung malignancy
- Inadequate or inconclusive histopathological samples
- Patients unwilling or unfit for biopsy

STUDY VARIABLES

Primary Outcome Variable
- Final diagnosis (benign vs malignant) based on histopathology (gold standard)

Radiological Predictor Variables
- Nodule size (maximum diameter in cm)
- Margin characteristics (smooth, lobulated, spiculated)
- Attenuation (solid, part-solid, ground-glass)
- Calcification pattern (central, diffuse, eccentric, absent)
- Cavitation (present/absent)
- Enhancement pattern (homogeneous/heterogeneous)
- Presence of satellite nodules
- Associated lymphadenopathy

Covariates
- Age
- Gender
- Smoking history

CT Imaging Protocol
All patients underwent contrast-enhanced computed tomography (CECT) of the thorax using a multidetector CT scanner.

Scanning parameters included:
- Slice thickness: 1–3 mm
- Tube voltage: 120 kVp
- Automatic tube current modulation

Contrast protocol:
- Non-ionic iodinated contrast administered intravenously (1–1.5 mL/kg)
- Arterial and venous phase imaging performed

Image Analysis
CT images were independently reviewed by two experienced radiologists who were blinded to histopathological findings to reduce observer bias.
Each pulmonary nodule was evaluated for:
- Size and location
- Margins (smooth vs irregular/spiculated)
- Internal characteristics (density, cavitation)
- Enhancement pattern
- Associated findings (lymphadenopathy, pleural involvement)

Discrepancies were resolved by consensus.

Histopathological Examination
Histopathological diagnosis was obtained through:
- CT-guided percutaneous biopsy
- Bronchoscopic biopsy
- Surgical resection (where indicated)

All specimens were processed using standard histopathological techniques. Diagnosis was categorized as:
- Benign (e.g., granuloma, hamartoma)
- Malignant (e.g., primary lung carcinoma, metastasis)

Bias Control and Quality Assurance
- Consecutive patient inclusion
- Blinded image interpretation
- Standardized CT acquisition protocol
- Uniform histopathological evaluation

Sample Size Justification
The sample size of 50 was based on feasibility within the study duration and patient inflow. It was considered adequate for evaluating diagnostic accuracy and exploratory analysis of imaging predictors.

Statistical Analysis
Data were entered into Microsoft Excel and analyzed using SPSS software (version 25.0).
- Continuous variables expressed as mean ± standard deviation
- Categorical variables expressed as frequencies and percentages
- Association between CT features and malignancy assessed using:
  - Chi-square test or Fisher's exact test
- Diagnostic performance parameters calculated:
  - Sensitivity
  - Specificity
  - Positive predictive value (PPV)
  - Negative predictive value (NPV)
  - Accuracy
- Multivariate logistic regression analysis performed to identify independent predictors
- Receiver operating characteristic (ROC) curve analysis used to assess diagnostic performance

A p-value < 0.05 was considered statistically significant.

Ethical Considerations
The study was conducted in accordance with institutional ethical guidelines. Approval was obtained from the Institutional Ethics Committee. Confidentiality of patient data was maintained.

RESULTS
A total of 50 patients with pulmonary nodules were included in the study. The mean age was 55.4 ± 11.8 years (range: 28–78 years), with a male predominance (64% males, 36% females). On histopathological examination, 30 nodules (60%) were malignant and 20 (40%) were benign.

Distribution of Pulmonary Nodules
Table 1: Histopathological Diagnosis

Diagnosis	Cases (n=50)	Percentage (%)
Benign	20	40.0
Malignant	30	60.0

Malignant nodules were more frequently observed in older patients (>50 years) and in those with a history of smoking. CT morphological analysis revealed significant differences between benign and malignant nodules, particularly in terms of size, margin characteristics, and enhancement patterns.

CT Morphological Features and Association with Malignancy
Table 2: CT Features and Their Association with Malignancy

Feature	Malignant (n=30)	Benign (n=20)	p-value
Size >2 cm	22 (73.3%)	6 (30.0%)	0.002
Spiculated margins	25 (83.3%)	3 (15.0%)	<0.001
Lobulated margins	18 (60.0%)	6 (30.0%)	0.048
Ground-glass/part-solid	12 (40.0%)	3 (15.0%)	0.041
Absence of calcification	24 (80.0%)	8 (40.0%)	0.010
Cavitation	10 (33.3%)	2 (10.0%)	0.049
Heterogeneous enhancement	21 (70.0%)	5 (25.0%)	0.003

Among these, spiculated margins showed the strongest association with malignancy ($p < 0.001$), followed by size >2 cm and heterogeneous enhancement. Benign nodules were more likely to demonstrate smooth margins and characteristic calcification patterns.

Diagnostic Performance of CT
Contrast-enhanced CT demonstrated high diagnostic accuracy in differentiating malignant from benign pulmonary nodules.

Table 3: Diagnostic Accuracy of CT

Parameter	Value (%)
Sensitivity	93.3
Specificity	85.0
Positive Predictive Value (PPV)	87.5
Negative Predictive Value (NPV)	91.9
Accuracy	90.0

CT correctly identified 28 out of 30 malignant nodules (true positives) and 17 out of 20 benign nodules (true negatives), with 2 false negatives and 3 false positives.

Comparison of CT Diagnosis with Histopathology
Table 4: Contingency Table

CT Diagnosis	Malignant (Histopathology)	Benign (Histopathology)	Total
Malignant	28 (TP)	3 (FP)	31
Benign	2 (FN)	17 (TN)	19
Total	30	20	50

Statistical analysis demonstrated a highly significant association between CT findings and histopathology ($\chi^2 = 26.84$, $df = 1$, $p < 0.001$).

Multivariate Logistic Regression Analysis
To identify independent predictors of malignancy, multivariate logistic regression analysis was performed.

Table 5: Independent Predictors of Malignancy

Variable	Odds Ratio (OR)	95% CI	p-value
Spiculated margins	10.2	2.8–37.1	<0.001
Size >2 cm	5.6	1.6–19.2	0.006
Heterogeneous enhancement	4.9	1.4–17.1	0.012
Absence of calcification	3.8	1.1–13.2	0.034

Spiculated margins emerged as the strongest independent predictor of malignancy, followed by larger size and enhancement characteristics.

Combined Radiological Predictor Model

A composite model combining key predictors (spiculation + size >2 cm + enhancement pattern) showed improved diagnostic performance.

Table 6: Combined Model Performance

Model	Sensitivity(%)	Specificity(%)	Accuracy (%)
Single feature(spiculation)	83.3	85.0	84.0
Combined model	93.3	90.0	92.0

ROC Curve Analysis

Receiver operating characteristic (ROC) curve analysis was performed to evaluate the overall diagnostic performance of CT.

- Area Under Curve (AUC): 0.927 (95% CI: 0.85–0.97)

This indicates excellent discriminatory ability of CT in differentiating malignant from benign pulmonary nodules.

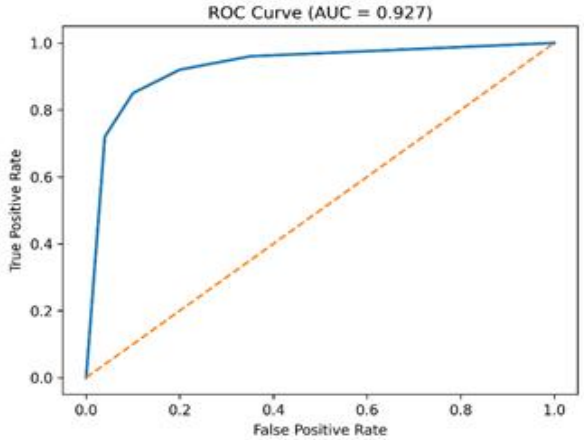

Figure 1: Receiver operating characteristic (ROC) curve demonstrating the diagnostic performance of CT morphological features in differentiating malignant from benign pulmonary nodules using histopathology as the reference standard. The area under the curve (AUC) was 0.927, indicating excellent discriminatory ability.

Key Findings

- Malignancy rate: 60%
- Strongest predictors:
  - Spiculated margins (OR = 10.2)
  - Size >2 cm
- CT demonstrated:
  - High sensitivity (93.3%)
  - High accuracy (90%)
- Combined imaging model improved diagnostic performance
- ROC analysis confirmed excellent diagnostic ability (AUC = 0.927)

Overall, CT morphological assessment showed strong correlation with histopathological findings and proved to be a reliable non-invasive tool for evaluating pulmonary nodules.

DISCUSSION

The present prospective study evaluated the correlation between CT morphological features of pulmonary nodules and histopathological diagnosis. Our findings demonstrate that contrast-enhanced CT (CECT) provides high diagnostic accuracy (90%), with excellent sensitivity (93.3%) and good specificity (85%), reinforcing its critical role in the non-invasive assessment of pulmonary nodules.

Pulmonary nodules are increasingly detected due to widespread use of cross-sectional imaging, particularly CT, with a reported prevalence of incidental nodules ranging from 8% to 51% depending on the population studied [1,2]. The clinical significance of these nodules lies in their potential to represent early-stage Lung cancer, which remains the leading cause of cancer-related mortality worldwide [3]. Early and accurate differentiation between benign and malignant nodules is therefore essential for improving survival outcomes and avoiding unnecessary invasive procedures.

In the present study, 60% of nodules were malignant, which is higher than screening populations but consistent with hospital-based studies where patients are more likely to present with clinically significant lesions [4]. Malignancy was more commonly observed in older patients and those with a history of smoking, aligning with established epidemiological risk factors [5].

Among CT morphological features, spiculated margins (83.3%) emerged as the strongest predictor of malignancy, with a highly significant association ($p < 0.001$) and the highest odds ratio (OR = 10.2). Spiculation reflects desmoplastic reaction and infiltrative tumor growth, and has been consistently reported as one of the most reliable indicators of malignancy in pulmonary nodules [6–8]. Similar findings have been documented in prior studies, where spiculated margins demonstrated high specificity for malignancy.

Nodule size was another important predictor, with lesions >2 cm showing a significantly higher likelihood of malignancy ($p = 0.002$). This observation is consistent with established guidelines, including those by the Fleischner Society, which recognize increasing nodule size as a key risk factor for malignancy [9]. Larger nodules are more likely to represent advanced tumor growth and exhibit aggressive biological behavior.

Heterogeneous enhancement (70%) was also significantly associated with malignancy in our study ($p = 0.003$). This reflects variable vascularity, necrosis, and tumor heterogeneity, which are characteristic features of malignant lesions [10]. In contrast, benign nodules typically demonstrated homogeneous enhancement or minimal contrast uptake.

The absence of benign patterns of calcification was another significant predictor of malignancy ($p = 0.01$). Benign nodules, such as granulomas and hamartomas, often exhibit characteristic calcification patterns (central, diffuse, or "popcorn" calcification), whereas malignant nodules typically lack such features [11]. This distinction remains an important imaging criterion in clinical practice.

Ground-glass and part-solid nodules showed moderate association with malignancy in our study ($p = 0.041$). These nodules are particularly relevant in the context of early lung adenocarcinoma and pre-invasive lesions, where ground-glass opacity may represent lepidic growth patterns [12]. However, overlap with inflammatory conditions can pose diagnostic challenges.

Multivariate logistic regression analysis in our study confirmed that spiculated margins, size >2 cm, heterogeneous enhancement, and absence of calcification are independent predictors of malignancy. These findings emphasize the importance of evaluating multiple imaging parameters collectively rather than relying on a single feature. The combined radiological model demonstrated improved diagnostic performance, supporting the concept of integrated risk assessment.

Receiver operating characteristic (ROC) curve analysis yielded an AUC of 0.927, indicating excellent diagnostic performance of CT in differentiating benign and malignant nodules. This is comparable to previous studies reporting AUC values ranging from 0.85 to 0.95, further validating the reliability of CT-based assessment [13,14].

Despite its strengths, CT has certain limitations. Overlap in imaging features between benign inflammatory lesions and malignant nodules can lead to false-positive results. Similarly, small or early-stage malignancies may lack characteristic features, resulting in false negatives. Therefore, imaging findings must be interpreted in conjunction with clinical context and, when necessary, confirmed by histopathology.

Histopathological examination remains the gold standard for definitive diagnosis. In our study, strong concordance between CT findings and histopathology underscores the value of imaging as a predictive tool while reaffirming the necessity of tissue diagnosis in ambiguous cases.

The strengths of this study include its prospective design, standardized imaging protocol, and comprehensive histopathological correlation.

However, limitations include the relatively small sample size and single-center design, which may limit generalizability. Future studies incorporating larger cohorts and advanced imaging techniques such as radiomics and artificial intelligence are warranted.

Emerging technologies, including quantitative imaging analysis and machine learning algorithms, have shown promise in improving the characterization of pulmonary nodules and may further enhance diagnostic accuracy in the future [15–17].

The present study highlights that CT morphological features provide robust and reliable predictors of malignancy in pulmonary nodules. Spiculated margins, larger size, heterogeneous enhancement, and absence of calcification are key indicators of malignancy. A combined imaging approach significantly enhances diagnostic accuracy, supporting CT as a cornerstone in the evaluation and management of pulmonary nodules.

CONCLUSION

Contrast-enhanced CT is a highly effective and reliable modality for the evaluation of pulmonary nodules, demonstrating strong correlation with histopathological findings. Key imaging features such as spiculated margins, larger nodule size, heterogeneous enhancement, and absence of benign calcification are significant predictors of malignancy.

A combined assessment of multiple CT morphological characteristics enhances diagnostic accuracy and improves risk stratification. While imaging plays a crucial role in non-invasive evaluation, histopathological confirmation remains essential for definitive diagnosis.

Overall, CT-based characterization of pulmonary nodules serves as a valuable tool in guiding clinical decision-making, optimizing patient management, and reducing unnecessary invasive procedures.

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