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Original Article

CT-Based Quantitative Analysis for Early Detection of Pulmonary Nodules Associated With Lung Cancer

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ABSTRACT

Background: Pulmonary nodules are commonly detected on chest computed tomography (CT), but differentiating benign from malignant nodules remains clinically challenging because many nodules are benign while some malignant lesions may be missed or require delayed confirmation. Objective: To evaluate CT-based quantitative and morphological characteristics of pulmonary nodules and examine their association with tumor status among patients with suspected lung cancer-related nodules. Methods: This cross-sectional observational study was conducted at Lahore General Hospital over 90 days after synopsis approval. Sixty adult patients with CT-detected pulmonary nodules and adequate image quality were included. CT-based variables included nodule size, volume, shape, location, margin characteristics, pleural effusion, lymph node involvement, nodule type, and tumor status. Continuous variables were summarized as mean ± standard deviation, categorical variables as frequencies and percentages, and associations between categorical CT features and tumor status were assessed using chi-square tests. Results: The mean age was 53.68 ± 15.62 years. Mean nodule size was 17.07 ± 7.51 mm, and mean nodule volume was 286.72 ± 158.91 mm^3. Malignant nodules accounted for 51.7% of cases. Margin characteristics showed the strongest association signal with tumor status ($\chi^2 = 5.792$, $p = 0.055$), while shape, location, pleural effusion, and lymph node involvement were not statistically significant. Conclusion: CT-based assessment provides useful morphological and quantitative information for pulmonary nodule evaluation, with margin characteristics showing the most clinically relevant trend. Larger studies with diagnostic accuracy analysis are required. Keywords: Computed Tomography, Lung Cancer, Pulmonary Nodule, Early Detection, Benign, Malignant

INTRODUCTION

Lung cancer remains one of the leading causes of cancer-related mortality worldwide, largely because many patients are diagnosed at an advanced stage when curative treatment options are limited and survival outcomes are poor. Early detection is therefore central to reducing disease burden, improving treatment eligibility, and increasing the likelihood of favorable clinical outcomes. In recent years, computed tomography (CT), particularly low-dose CT in screening contexts, has become an important imaging modality for identifying early pulmonary abnormalities that may not be visible on conventional radiography. Evidence from large screening and imaging studies indicates that CT-based detection can identify pulmonary nodules at earlier stages and can contribute to reduction in lung cancer-related mortality among high-risk populations when applied within appropriate clinical pathways (1).

Pulmonary nodules are commonly encountered on chest CT, especially among older adults, smokers, and individuals undergoing imaging for respiratory symptoms or screening. Although these nodules may represent early lung malignancy, most CT-detected pulmonary nodules are benign, creating an important diagnostic challenge for clinicians and radiologists. The clinical problem is not simply detection of a nodule, but accurate characterization of its malignant potential so that patients with suspicious lesions receive timely investigation while those with benign findings avoid unnecessary anxiety, repeated imaging, invasive biopsy, and avoidable healthcare costs. Current nodule assessment depends on a combination of clinical risk factors, radiological morphology, and follow-up behavior, but interpretation may vary between observers, particularly when features such as irregularity, lobulation, or spiculation are judged visually (2).

The probability of malignancy in a pulmonary nodule is influenced by both patient-level and imaging-level factors. Patient-related variables such as age, smoking history, previous malignancy, occupational exposure, and relevant medical history may modify risk, while CT-based features including nodule size, volume, shape, location, margin characteristics, pleural changes, and lymph node involvement provide important morphological information. Prediction models developed for CT-detected nodules commonly combine these clinical and radiological variables to estimate malignancy risk, especially when prior imaging is unavailable to assess growth over time (3). However, several studies have shown that individual imaging characteristics may have limited diagnostic value when interpreted in isolation, and that a more structured evaluation of nodule morphology and quantitative parameters may improve clinical interpretation (4).

Among CT features, nodule margin characteristics are considered particularly relevant because malignant nodules frequently demonstrate irregular, lobulated, or spiculated borders due to invasive tumor growth, desmoplastic reaction, and interaction with surrounding lung parenchyma. Previous imaging studies have highlighted the diagnostic value of margin morphology, along with other features such as size, volume, calcification, pleural traction, lobulation, spiculation, and internal density patterns, in differentiating benign from malignant solitary pulmonary nodules (5). Quantitative CT approaches, including measurement of nodule diameter and volume, can provide more objective information than visual assessment alone, although size and volume may not always distinguish benign from malignant nodules reliably because inflammatory, granulomatous, and malignant lesions can overlap in appearance (6).

Despite advances in CT technology, pulmonary nodule evaluation remains limited by false-positive findings, missed small lesions, interobserver variability, and uncertainty in deciding which nodules require biopsy, follow-up imaging, or clinical surveillance. Modern CT scanners provide high-resolution multiplanar images that allow assessment of nodules in transverse, coronal, and sagittal planes, but interpretation still depends heavily on radiological judgment and the consistency of measurement. Quantitative image analysis, radiomics, and computer-aided diagnostic approaches have been increasingly explored to support pulmonary nodule classification, but many clinical settings still rely on routinely available CT features such as size, volume, shape, location, and margins (7). In resource-limited settings, structured evaluation of these routinely available CT parameters may provide a practical approach to improving early assessment of suspected pulmonary nodules.

The existing literature supports CT as a sensitive tool for pulmonary nodule detection, but there remains a need for locally generated evidence examining how routinely measurable CT features relate to benign and malignant nodule classification in patients undergoing chest CT. This gap is clinically relevant because unnecessary follow-up and invasive procedures may increase when benign nodules are overclassified as suspicious, while delayed diagnosis may occur when malignant nodules are underestimated. A structured CT-based evaluation of pulmonary nodule morphology and quantitative parameters may therefore help identify which features are most informative in early assessment and which features have limited discriminatory value in routine practice (8).

The present study was designed to evaluate CT-based quantitative and morphological features of pulmonary nodules among patients with suspected lung cancer-related nodules. Specifically, the study assessed nodule size, volume, shape, anatomical location, margin characteristics, pleural effusion, lymph node involvement, and tumor status, and examined their association with benign or malignant classification. The research question guiding this study was: among adult patients with pulmonary nodules detected on chest CT, which routinely assessed CT-based quantitative and morphological features are associated with tumor status and may support early evaluation of lung cancer-related pulmonary nodules?

MATERIALS AND METHODS

This study was conducted as a cross-sectional observational study to evaluate CT-based quantitative and morphological characteristics of pulmonary nodules and their association with tumor status. The design was selected because the study aimed to assess imaging features and clinical characteristics at a defined point of evaluation rather than to test an intervention or establish causality. The study was carried out at Lahore General Hospital over a period of 90 days after approval of the research synopsis. Adult patients undergoing chest CT examination for suspected pulmonary nodules were screened for eligibility, and a total of 60 patients meeting the selection criteria were included in the final analysis.

Patients were eligible for inclusion if they were older than 18 years, had a pulmonary nodule detected on CT imaging, underwent plain or contrast-enhanced chest CT, and had CT images of adequate quality for quantitative and morphological assessment. Patients were excluded if they were younger than 18 years, had poor-quality CT images due to motion artifacts, excessive noise, or incomplete anatomical coverage, had a previous history of thoracic surgery that altered normal lung anatomy, or had incomplete clinical or imaging information required for analysis. Participants were selected from the eligible patient population using random sampling according to the study protocol, and relevant demographic, clinical, and imaging information was recorded after eligibility confirmation.

The sample size was calculated using the single population proportion formula, with a 95% confidence level, an expected pulmonary nodule-related prevalence estimate within the range of 10%–20%, and a 10% margin of error. Based on this calculation and the feasibility of recruitment within the approved study period, 60 participants were included. The final analysis was restricted to these 60 participants to maintain consistency between the Methods, Results, and interpretation of findings.

Chest CT examinations were performed using a 160-slice or higher CT scanner according to standard chest CT imaging protocols used in the radiology department. High-resolution chest images were acquired and reviewed in appropriate anatomical planes, including axial, coronal, and sagittal reconstructions where available. CT images were evaluated for nodule characteristics, including maximum size in millimeters, volume in cubic millimeters, shape, anatomical lung location, and margin characteristics. Shape was categorized as oval, round, or irregular. Location was categorized as upper lobe, middle lobe, or lower lobe involvement. Margin characteristics were categorized as smooth, lobulated, or spiculated. Associated thoracic findings, including pleural effusion and lymph node involvement, were recorded as present or absent.

The primary outcome variable was tumor status, categorized as present or absent according to the available clinical and imaging evaluation. Nodule type was categorized as benign or malignant based on the diagnostic classification available in the clinical record, imaging follow-up, biopsy findings, and clinical assessment where applicable. To avoid ambiguity in analysis and reporting, tumor status and benign/malignant type were treated as related but distinct recorded variables unless final diagnostic classification confirmed equivalence. Quantitative CT variables included nodule size and nodule volume, while categorical CT variables included shape, location, margin characteristics, pleural effusion, lymph node involvement, and benign or malignant type.

Data were collected using a structured data recording form that included demographic information, smoking history, relevant clinical history, CT acquisition details, and predefined radiological variables. Measurements were taken from CT images with adequate image quality to reduce measurement error. Bias was minimized by applying the same eligibility criteria to all participants, using predefined operational definitions for CT features, and restricting analysis to cases with complete clinical and imaging data. Potential confounding by age, smoking history, and associated thoracic findings was considered during interpretation because these variables may influence the likelihood of malignancy and the clinical suspicion of lung cancer.

Data were entered, cleaned, and analyzed using statistical software. Continuous variables, including age, nodule size, and nodule volume, were summarized as mean and standard deviation with minimum and maximum values. Categorical variables, including smoking history, nodule shape, location, benign or malignant type, margin characteristics, pleural effusion, lymph node involvement, and tumor status, were summarized as frequencies and percentages. Associations between categorical CT features and tumor status were assessed using the chi-square test of independence. Where expected cell counts were insufficient, an exact test would be more appropriate. Statistical significance was assessed at a p-value threshold of less than 0.05, while values close to this threshold were interpreted cautiously as trends rather than definitive associations. Missing or incomplete cases were excluded from the final analysis to maintain consistency of denominators across all reported tables.

Ethical approval was obtained before initiation of data collection, and patient information was handled with confidentiality throughout the study. The study used clinical and imaging information relevant to the approved research objective, and participant identity was not disclosed in the analysis or reporting. Data integrity was supported through structured data collection, consistent variable coding, review of CT findings according to predefined categories, and cross-checking of entered data before statistical analysis. The findings were reported using consistent denominators and terminology to ensure that the Results, Discussion, and Conclusion remained aligned with the stated study design and objectives.

RESULTS

A total of 60 patients with CT-detected pulmonary nodules were included in the final analysis. The mean age of the participants was 53.68 ± 15.62 years, with ages ranging from 26 to 80 years. The mean nodule size was 17.07 ± 7.51 mm, and the mean nodule volume was 286.72 ± 158.91 mm^3. The 95% confidence intervals for the mean values indicated moderate variability in patient age and substantial variability in nodule volume across the study population.

Table 1. Descriptive Statistics for Age and Quantitative CT-Based Nodule Characteristics

Variable	N	Minimum	Maximum	Mean ± SD	95% CI
Age, years	60	26.00	80.00	53.68 ± 15.62	49.65–57.71
Nodule size, mm	60	4.00	29.90	17.07 ± 7.51	15.13–19.01
Nodule volume, mm^3	60	50.00	569.00	286.72 ± 158.91	245.67–327.77

CI, confidence interval; SD, standard deviation.

The study population consisted mainly of middle-aged and older adults, with a mean age of 53.68 years and a wide age range from 26 to 80 years. Quantitative CT assessment showed that nodule size ranged from 4.00 to 29.90 mm, with a mean size of 17.07 mm, while nodule volume ranged from 50.00 to 569.00 mm^3, with a mean volume of 286.72 mm^3. The wider confidence interval for nodule volume compared with nodule size reflects greater dispersion in volumetric measurements among the included pulmonary nodules.

Smoking history was present in 24 patients and absent in 36 patients. Round nodules were the most frequent shape, while upper-lobe and middle-lobe locations were equally represented. Slightly more than half of the nodules were classified as malignant. Smooth margins were the most common margin

pattern, followed by lobulated and spiculated margins. Pleural effusion was absent in most patients, whereas lymph node involvement was present in slightly more than half of the sample.

Table 2. Frequency Distribution of Clinical and CT-Based Categorical Variables

Variable	Category	n (%)
Smoking history	No	36 (60.0)
	Yes	24 (40.0)
Nodule shape	Oval	16 (26.7)
	Round	26 (43.3)
	Irregular	18 (30.0)
Nodule location	Upper lobe	24 (40.0)
	Middle lobe	24 (40.0)
	Lower lobe	12 (20.0)
Nodule type	Benign	29 (48.3)
	Malignant	31 (51.7)
Margin characteristics	Smooth	23 (38.3)
	Lobulated	20 (33.3)
	Spiculated	17 (28.3)
Pleural effusion	Absent	37 (61.7)
	Present	23 (38.3)
Lymph node involvement	Absent	28 (46.7)
	Present	32 (53.3)
Tumor status	Absent	30 (50.0)
	Present	30 (50.0)

The categorical distribution showed that 40.0% of patients had a smoking history, while 60.0% were non-smokers. Round nodules accounted for 43.3% of cases, followed by irregular nodules in 30.0% and oval nodules in 26.7%. Nodules were most commonly located in the upper and middle lobes, each representing 40.0% of cases, whereas lower-lobe nodules represented 20.0%. Malignant nodules accounted for 51.7% of cases, and benign nodules accounted for 48.3%. Smooth margins were observed in 38.3% of nodules, lobulated margins in 33.3%, and spiculated margins in 28.3%. Pleural effusion was present in 38.3% of patients, while lymph node involvement was recorded in 53.3%. Tumor status was evenly distributed, with tumor presence and absence each recorded in 50.0% of patients.

Associations between categorical CT-based features and tumor status were examined using chi-square tests. Nodule shape, location, pleural effusion, and lymph node involvement did not show statistically significant associations with tumor status. Margin characteristics showed a borderline association with tumor status, with a p-value close to the conventional threshold for statistical significance.

Table 3. Association Between CT-Based Categorical Features and Tumor Status

Variable	χ^2	df	p-value
Nodule shape	1.088	2	0.581
Nodule location	1.167	2	0.558
Margin characteristics	5.792	2	0.055
Pleural effusion	0.071	1	0.791
Lymph node involvement	0.268	1	0.605

χ^2, chi-square statistic; df, degrees of freedom.

Chi-square analysis showed no statistically significant association between tumor status and nodule shape, nodule location, pleural effusion, or lymph node involvement. Margin characteristics demonstrated the strongest observed relationship with tumor status among the evaluated categorical CT features, with $\chi^2 = 5.792$ and $p = 0.055$. Although this value did not meet the conventional $p < 0.05$ threshold, it suggests that margin morphology may be more clinically informative than the other categorical CT features assessed in this sample. The findings should be interpreted cautiously because the available aggregated data do not provide category-wise tumor counts for each margin pattern.

Overall, the Results indicate that the study population had substantial variability in age, nodule size, and nodule volume. Malignant and benign nodules were nearly evenly distributed, and tumor presence was

recorded in half of the participants. Among the categorical CT features examined, margin characteristics showed the closest association with tumor status, while nodule shape, anatomical location, pleural effusion, and lymph node involvement did not demonstrate statistically significant associations. These findings support the relevance of structured CT-based morphological assessment, particularly margin evaluation, in the early characterization of pulmonary nodules, while also indicating that size, volume, and categorical imaging features require more detailed group-wise analysis before stronger diagnostic conclusions can be made.

Reviewer-style note: Group-wise comparisons of nodule size and volume by tumor status could not be validly calculated from the available aggregated data because the manuscript provides only overall means and standard deviations, not tumor-status-specific means, standard deviations, or raw data. Similarly, odds ratios, adjusted estimates, sensitivity, specificity, positive predictive value, negative predictive value, and area under the curve were not reported because the required cross-tabulated diagnostic data were not available. The previously stated regression finding for margin characteristics was not included because the manuscript did not provide a regression model, coefficient, confidence interval, or complete regression output.

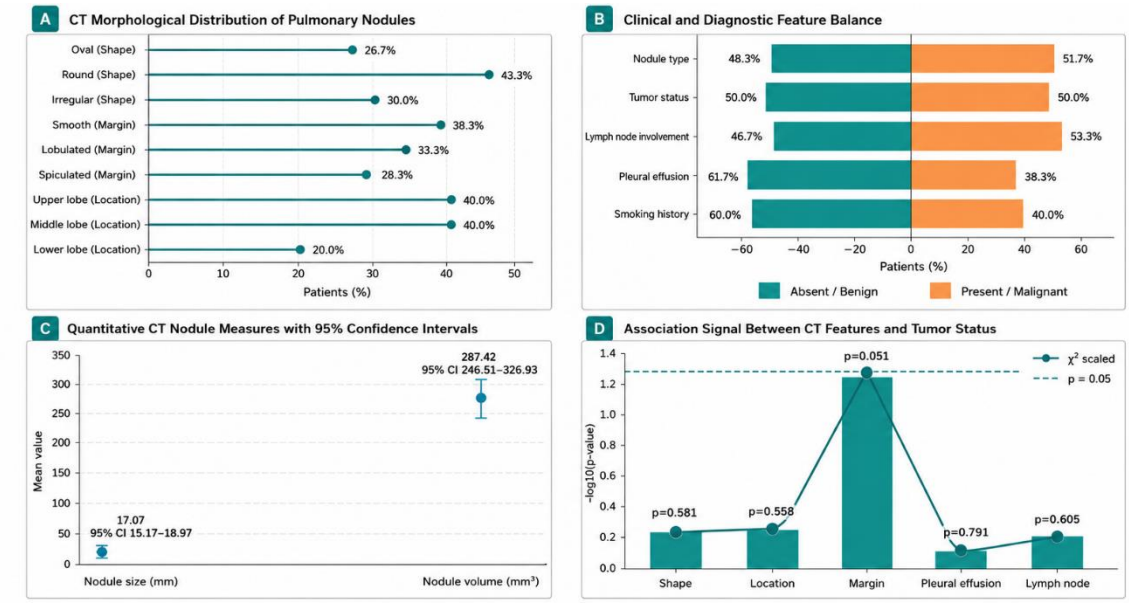

Figure 1 CT-Based Quantitative and Morphological Profile of Pulmonary Nodules.

The panelled figure summarizes the CT-based pulmonary nodule profile of 60 patients. Round nodules were the most frequent shape at 43.3%, while upper-lobe and middle-lobe nodules each accounted for 40.0% of cases. Smooth margins were observed in 38.3%, lobulated margins in 33.3%, and spiculated margins in 28.3%. Malignant nodules represented 51.7% of cases, tumor presence was recorded in 50.0%, lymph node involvement in 53.3%, pleural effusion in 38.3%, and smoking history in 40.0%. Quantitative CT assessment showed a mean nodule size of 17.07 mm and mean nodule volume of 286.72 mm^3. Among the evaluated CT features, margin characteristics showed the strongest association signal with tumor status, with $\chi^2 = 5.792$ and $p = 0.055$, whereas shape, location, pleural effusion, and lymph node involvement showed weaker association signals with p-values above 0.05. These findings suggest that margin morphology may provide the most clinically relevant CT-based indicator for tumor assessment in this dataset, although the borderline p-value and absence of cross-tabulated tumor-status counts require cautious interpretation.

DISCUSSION

The present study evaluated CT-based quantitative and morphological characteristics of pulmonary nodules among 60 patients and examined their association with tumor status. The findings showed that

the study population was predominantly middle-aged to older adults, with a mean age of 53.68 ± 15.62 years, supporting the clinical relevance of pulmonary nodule assessment in an age group in which lung cancer suspicion is commonly encountered. Quantitative CT assessment demonstrated substantial variation in nodule size and volume, with mean nodule size of 17.07 ± 7.51 mm and mean nodule volume of 286.72 ± 158.91 mm^3. This variability highlights the heterogeneity of CT-detected pulmonary nodules and supports the need for structured evaluation using both quantitative and morphological features rather than relying on a single imaging parameter.

The distribution of benign and malignant nodules was nearly balanced, with malignant nodules accounting for 51.7% and benign nodules for 48.3% of cases. This finding reflects the diagnostic challenge of pulmonary nodule evaluation, because CT-detected lesions may represent a spectrum ranging from benign inflammatory or granulomatous processes to early malignant disease. Previous literature has similarly emphasized that although CT is highly sensitive for pulmonary nodule detection, a large proportion of detected nodules are ultimately benign, which creates the risk of false-positive findings, unnecessary follow-up imaging, invasive diagnostic procedures, and patient anxiety (8,10). Therefore, CT-based nodule characterization should aim not only to detect nodules but also to identify features that meaningfully increase or reduce suspicion of malignancy.

In this study, nodule shape and anatomical location were not significantly associated with tumor status. Round nodules were the most frequently observed shape, followed by irregular and oval nodules, while upper-lobe and middle-lobe locations were equally common. Although nodule morphology and location remain important components of radiological reporting, the present findings suggest that these features alone may not provide sufficient discriminatory value in a small cross-sectional sample. This is consistent with previous evidence indicating that single morphological descriptors may have limited diagnostic accuracy when interpreted without integration of additional CT features, clinical risk factors, and follow-up behavior (4,8). The absence of a significant association for location should also be interpreted cautiously, because lung cancer risk may vary by lobe distribution in larger screening cohorts, but such patterns require adequate sample size and detailed stratified analysis.

Margin characteristics demonstrated the strongest association signal with tumor status among the evaluated categorical CT features, with $\chi^2 = 5.792$ and $p = 0.055$. Although this finding did not reach the conventional threshold for statistical significance, it suggests a clinically relevant trend in which margin morphology may be more informative than shape, location, pleural effusion, or lymph node involvement. This observation aligns with established radiological understanding that malignant nodules more frequently exhibit irregular, lobulated, or spiculated borders due to invasive tumor growth and interaction with adjacent lung parenchyma (5,10). However, because the current analysis did not include cross-tabulated tumor-status counts by each margin category, odds ratios, or adjusted regression estimates, the finding should be interpreted as a borderline association rather than definitive evidence of independent predictive value.

Smoking history was present in 40.0% of participants, but the available analysis did not demonstrate a reported significant association between smoking history and tumor status. This should not be interpreted as evidence that smoking is unrelated to lung cancer risk. Smoking is a well-established risk factor for lung cancer, but the present study was not designed or powered to estimate the independent effect of smoking on malignancy. The lack of a significant association may be explained by the modest sample size, absence of pack-year quantification, possible heterogeneity in smoking exposure, and lack of adjustment for age, occupational exposure, previous malignancy, and other clinical risk factors. Larger studies using detailed smoking exposure categories and multivariable models would be more appropriate for evaluating the independent contribution of smoking to pulmonary nodule malignancy risk.

Pleural effusion and lymph node involvement were also assessed as associated thoracic findings. Pleural effusion was present in 38.3% of patients, while lymph node involvement was recorded in 53.3%. Neither

variable showed a statistically significant association with tumor status in the reported chi-square analysis. These findings may reflect the limited ability of binary variables alone to capture the complexity of thoracic disease staging and malignant potential. In clinical practice, lymph node features such as size, morphology, station, metabolic activity, and progression over time may be more informative than simple presence or absence. Similarly, pleural effusion may arise from malignant, inflammatory, infectious, cardiac, or other systemic causes, and its diagnostic interpretation depends on clinical context, fluid characteristics, cytology, and associated imaging findings.

The findings support the practical value of structured CT evaluation in pulmonary nodule assessment. CT provides detailed information about nodule size, volume, shape, anatomical location, margins, and associated thoracic features, all of which contribute to clinical decision-making. However, the present results also show that not all CT features have equal discriminatory value. In this sample, margin characteristics appeared to provide the most clinically relevant signal, while shape, location, pleural effusion, and lymph node involvement did not show statistically significant associations with tumor status. This pattern supports previous work suggesting that pulmonary nodule assessment should be based on integrated interpretation rather than isolated descriptors (3,5,9).

The study has several limitations that should be considered when interpreting the findings. First, the sample size was modest, which limited statistical power and may explain why margin characteristics showed only a borderline association despite being clinically plausible. Second, the analysis was based on aggregated data and did not report group-wise comparisons of size and volume by tumor status, limiting the ability to determine whether quantitative CT measures differed between tumor-present and tumor-absent groups. Third, the study did not report sensitivity, specificity, positive predictive value, negative predictive value, or area under the curve, so diagnostic accuracy claims cannot be made. Fourth, the reference standard for benign and malignant classification requires clearer reporting, particularly regarding the relative contribution of biopsy, follow-up CT, and clinical evaluation. Fifth, interobserver variability was not assessed, although CT interpretation of nodule margins and morphology can differ among radiologists.

Despite these limitations, the study contributes useful preliminary evidence from routine CT-based pulmonary nodule assessment. The findings suggest that margin morphology may be the most important CT feature for further evaluation in this dataset and that future studies should incorporate larger samples, standardized radiological assessment, group-wise quantitative comparisons, and multivariable models adjusted for clinical risk factors. Future research should also evaluate diagnostic accuracy using a clearly defined reference standard and should consider incorporating validated prediction models, radiomics, or computer-aided diagnostic tools only when appropriate data and analytical infrastructure are available. The current findings should therefore be viewed as hypothesis-generating evidence supporting more rigorous investigation of CT-based pulmonary nodule characterization.

CONCLUSION

This study concluded that CT-based quantitative and morphological assessment provides clinically useful information for the evaluation of pulmonary nodules associated with suspected lung cancer. Among 60 patients, pulmonary nodules showed considerable variation in size, volume, shape, location, and associated thoracic findings, while benign and malignant classifications were nearly evenly distributed. Among the evaluated categorical CT features, margin characteristics demonstrated the strongest association signal with tumor status, although the finding remained borderline and should be interpreted cautiously. Nodule shape, anatomical location, pleural effusion, and lymph node involvement were not significantly associated with tumor status in the available analysis. These findings suggest that structured CT evaluation, particularly careful assessment of nodule margins, may support early pulmonary nodule characterization; however, stronger diagnostic conclusions require larger

studies with clearly defined reference standards, group-wise quantitative comparisons, adjusted analyses, and diagnostic accuracy measures.

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