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Chest CT in Pulmonary Fibrosis: A Narrative Review of Imaging Patterns and Their Prognostic Significance

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ABSTRACT

Pulmonary fibrosis represents a heterogeneous group of interstitial lung diseases (ILDs) marked by progressive scarring of the lung parenchyma and declining respiratory function. High-resolution computed tomography (HRCT) plays a pivotal role in diagnosing and managing fibrotic ILDs, particularly idiopathic pulmonary fibrosis (IPF), connective tissue disease-associated ILD (CTD-ILD), and chronic hypersensitivity pneumonitis (CHP). This narrative review explores key imaging patterns observable on chest CT and their prognostic implications across these major subtypes. We conducted a literature review of studies published between 2010 and 2025 using PubMed, Scopus, and Web of Science, focusing on CT features, subtype differentiation, prognostic imaging biomarkers, and recent innovations in radiomics and artificial intelligence (AI). Characteristic HRCT findings, such as honeycombing, reticulation, ground-glass opacities, and traction bronchiectasis, were analyzed in the context of usual interstitial pneumonia (UIP) and nonspecific interstitial pneumonia (NSIP) patterns. UIP pattern on HRCT is strongly associated with IPF and confers a worse prognosis compared to NSIP or other non-UIP patterns. Quantitative imaging methods and automated CT analytics offer objective measurements of fibrosis extent and have demonstrated promising correlations with physiologic parameters such as forced vital capacity (FVC) and diffusing capacity for carbon monoxide (DLCO). Emerging AI tools enhance disease classification, monitor progression, and support clinical decision-making. Despite substantial advances, challenges such as inter-reader variability, limited access to quantitative software, and unstandardized CT protocols persist. Furthermore, AI applications require broader validation in multicenter cohorts before routine implementation. This review highlights the central role of HRCT in the multidisciplinary evaluation of pulmonary fibrosis. It underscores the prognostic significance of specific imaging features and advocates for standardized imaging interpretation and the integration of AI to refine diagnostic accuracy and therapeutic planning.

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Introduction

Pulmonary fibrosis consists of a group of interstitial lung diseases (ILDs) characterized by chronic and progressive scarring of lung tissue (1). This fibrotic process impairs gas

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exchange and worsens respiratory function, often leading to respiratory failure (2). Among the various forms of pulmonary fibrosis, idiopathic pulmonary fibrosis (IPF) is the most severe and prevalent subtype, associated with a poor prognosis and a median survival ranging from three to five years following diagnosis (3).

High-resolution computed tomography (HRCT) has emerged as an essential imaging tool in the diagnostic workup of patients with suspected pulmonary fibrosis (4). It offers superior anatomical detail of the lung parenchyma and is instrumental not only in identifying fibrotic changes but also in distinguishing between ILD subtypes (5). HRCT findings such as honeycombing, reticular opacities, ground-glass areas, and traction bronchiectasis allow for classification into established imaging patterns, including usual interstitial pneumonia (UIP) and nonspecific interstitial pneumonia (NSIP), among others (6).

Recognition of a UIP pattern on HRCT is particularly important, as it strongly suggests IPF and is linked to a more aggressive disease course and worse outcomes compared to other ILDs (7). In many cases, a confident radiological diagnosis based on a typical UIP pattern can eliminate the need for invasive diagnostic procedures like surgical lung biopsy (8). Furthermore, chest CT findings provide prognostic insights. Features such as the extent of fibrosis, presence of honeycombing, and severity of bronchiectasis have all been associated with disease progression and mortality risk (9). In recent years, advancements in imaging analytics—particularly quantitative CT (QCT), machine learning techniques, and radiomics—have further enhanced the prognostic capabilities of CT imaging (10, 11). These tools enable objective and reproducible measurements of fibrotic burden and can support clinical decision-making by providing additional prognostic data (12). Despite these advances, challenges such as variability in image interpretation and the need for standardized reporting criteria continue to limit the widespread clinical adoption of advanced CT analytics.

Given the central role of HRCT in both the diagnosis and management of pulmonary fibrosis, a comprehensive review of characteristic imaging patterns and their relationship to clinical outcomes is timely. While numerous studies have explored these topics individually, there is a need for an integrated summary of how chest CT findings can inform both diagnosis and prognosis across various forms of pulmonary fibrosis. This narrative review aims to investigate current knowledge on chest CT features in pulmonary fibrosis, with a specific focus on identifying key imaging patterns and evaluating their relevance in predicting clinical outcomes. This synthesis is intended to support radiologists, pulmonologists, and multidisciplinary care teams in making more informed diagnostic and therapeutic decisions.

A comprehensive literature search was conducted using PubMed, Scopus, and Web of Science databases to identify relevant English-language publications. The search covered articles published between January 2010 and March 2025, using combinations of the following keywords and Medical Subject Headings (MeSH) terms: “pulmonary fibrosis,” “interstitial lung disease,” “idiopathic pulmonary fibrosis,” “chest CT,” “HRCT,” “imaging patterns,” “UIP,” “NSIP,” “prognosis,” and “quantitative imaging”.

Included studies were selected based on relevance to one or more of the following themes: characterization of CT imaging features in pulmonary fibrosis, association between imaging patterns and histopathological subtypes, prognostic value of specific CT findings or scoring systems, and emerging imaging tools such as quantitative CT analysis or artificial intelligence applications.

We prioritized peer-reviewed clinical studies, radiologic reviews, guidelines, and expert consensus statements. Case reports and small case series were excluded unless they provided unique imaging insights. Additional sources were identified through backward citation tracking of key articles.

The selected literature was organized thematically to address key review objectives, including: (1) the role of CT in diagnosing pulmonary fibrosis subtypes, (2) the radiologic distinction between patterns such as UIP and NSIP, and (3) the prognostic significance of various CT features.

1- Overview of Pulmonary Fibrosis

Pulmonary fibrosis encompasses a diverse group of ILDs characterized by varying degrees of alveolar epithelial injury, fibroblast proliferation, and extracellular matrix deposition, ultimately resulting in irreversible scarring of lung parenchyma and impaired gas exchange. While the etiologies differ, the common pathological hallmark across subtypes is progressive fibrosis, which is associated with significant morbidity and mortality (13, 14) (Table 1).

1-1. Idiopathic Pulmonary Fibrosis (IPF)

IPF is the most prevalent and severe form of fibrosing ILD and serves as the prototypical model for progressive fibrotic lung disease. It is defined by the presence of a usual UIP pattern on histopathology or HRCT in the absence of a known cause (3, 15). IPF primarily affects older adults, typically over 60 years of age, and is more common in males and individuals with a history of cigarette smoking. Clinically, IPF presents with chronic exertional dyspnea and a persistent dry cough. Prognosis remains poor despite advances in anti-fibrotic therapy, with a median survival of approximately 3 to 5 years from diagnosis (16,17).

1-2. Connective Tissue Disease-Associated ILD (CTD-ILD)

Several autoimmune diseases, such as rheumatoid arthritis, systemic sclerosis, and polymyositis/dermatomyositis, can be complicated by pulmonary fibrosis. These CTD-associated ILDs display a broader spectrum of radiologic and histologic patterns, with both UIP and NSIP commonly observed (18, 19). The presence of fibrosis in this context significantly worsens the patient's prognosis and quality of life. However, compared to IPF, the disease course is often more variable and may respond better to immunosuppressive or anti-fibrotic treatment, particularly in NSIP-dominant cases (19,20).

Table 1. Summary of Key Pulmonary Fibrosis Subtypes.

Subtype	Underlying Cause	Typical HRCT Features	Common Clinical Manifestations	Prognostic Outlook
Idiopathic Pulmonary Fibrosis (IPF)	Cause unknown	Subpleural and basal-predominant fibrosis, honeycombing, traction bronchiectasis (UIP pattern)	Persistent dry cough, progressive breathlessness, mostly affects older males	Unfavorable; median survival ranges from 3 to 5 years
CTD-Related ILD	Autoimmune disorders (e.g., rheumatoid arthritis, systemic sclerosis, dermatomyositis)	Can show UIP or NSIP features; may have ground-glass opacities or fibrosis	Symptoms often related to systemic disease; dyspnea and fatigue common	More variable; NSIP tends to have better outcomes than UIP
Chronic Hypersensitivity Pneumonitis (CHP)	Long-term exposure to inhaled allergens (e.g., bird proteins, mold spores)	Mosaic attenuation, lobular air trapping, centrilobular nodules; may mimic UIP in advanced stages	Cough, dyspnea, often with a known exposure history; insidious symptom onset	Mixed prognosis depending on fibrosis extent and exposure cessation
Shared Features (All Subtypes)	Varies (idiopathic, autoimmune, environmental)	Imaging depends on subtype but often includes fibrotic changes	Reduced DLCO, restrictive pattern on PFT, exercise intolerance	Worse outcomes associated with UIP, rapid decline, or comorbidities

Abbreviations: HRCT: High-Resolution Computed Tomography; **UIP:** Usual Interstitial Pneumonia; **NSIP:** Nonspecific Interstitial Pneumonia; **DLCO:** Diffusing Capacity for Carbon Monoxide; **PFT:** Pulmonary Function Test; ILD: Interstitial Lung Disease.

1-3. Chronic Hypersensitivity Pneumonitis (CHP)

Chronic hypersensitivity pneumonitis is an immune-mediated ILD caused by repeated inhalation of environmental antigens. Over time, persistent antigen exposure may result in fibrotic remodeling, often presenting with a combination of fibrotic and inflammatory changes on HRCT, such as mosaic attenuation, air trapping, and centrilobular nodules (21, 22). Fibrotic CHP can mimic IPF in advanced stages, particularly when a UIP pattern is present, complicating diagnosis and management. Prognosis is heterogeneous and depends on the extent of fibrosis and continued antigen exposure (23, 24).

1-4. Clinical Features and Prognosis

Regardless of the underlying etiology, fibrotic ILDs share overlapping clinical features such as progressive dyspnea, reduced exercise tolerance, and impaired pulmonary function, particularly a restrictive ventilatory pattern and reduced diffusing capacity for carbon monoxide (DLCO). Prognosis is influenced by several factors, including radiologic pattern (e.g., UIP vs. NSIP), rate of functional decline, and comorbid conditions such as pulmonary hypertension. Among these, the UIP pattern—regardless of the clinical context—is consistently associated with worse outcomes (9, 25, 26).

2- Role of Chest CT in Pulmonary Fibrosis

HRCT plays a central role in the assessment of ILDs, particularly fibrotic subtypes such as IPF, CTD-ILD, and CHP. Unlike conventional chest radiography, HRCT provides detailed visualization of lung architecture, enabling accurate identification of fibrotic changes and helping differentiate among ILD subtypes (27).

2-1. Diagnostic Utility

HRCT has become an indispensable tool in the diagnosis of pulmonary fibrosis, often serving as a surrogate for histopathological confirmation when typical imaging features are present. The 2018 international IPF guidelines emphasize that a diagnosis of IPF can be confidently made without surgical biopsy if HRCT shows a "definite UIP" pattern. This pattern is characterized by basal and subpleural predominance, reticulation, and honeycombing, with minimal ground-glass opacification and absence of features suggesting alternative diagnoses (3, 6). The ability of CT to detect subtle fibrosis also facilitates early diagnosis, which is critical given the progressive nature of many ILDs.

2-2. Differentiation Between Subtypes

One of the key strengths of HRCT lies in its capacity to distinguish between different subtypes of pulmonary fibrosis, based on distinct imaging patterns. For example, IPF typically presents with a UIP pattern, while CTD-ILDs more often show a NSIP pattern, which features uniform ground-glass opacities and volume loss, usually with less honeycombing (28, 29). CHP may demonstrate a combination of fibrosis and air-trapping, with imaging features such as mosaic attenuation, centrilobular nodules, and lobular sparing, aiding in its differentiation from IPF even when fibrosis is advanced (9). Recognizing these patterns is essential not only for diagnosis but also for prognostication, as certain imaging patterns—particularly UIP—are associated with worse outcomes regardless of the underlying disease (30).

2-3. Guiding Biopsy and Treatment Decisions

Chest CT also serves as a valuable tool for guiding further diagnostic and therapeutic steps. When HRCT findings are inconclusive or show a pattern indeterminate for UIP, it helps localize areas of active disease for targeted surgical or cryobiopsy, improving diagnostic yield while minimizing patient risk (31). Moreover, CT findings often influence treatment strategies. For instance, patients with a UIP pattern are more likely to benefit from antifibrotic agents like nintedanib or pirfenidone, while those with inflammatory patterns (e.g., NSIP) may respond better to immunosuppressive therapies (32). CT imaging is also used to assess disease progression and monitor treatment

response, either qualitatively or through emerging quantitative imaging tools.

In summary, HRCT is not merely a diagnostic adjunct but a cornerstone of modern pulmonary fibrosis evaluation. It informs diagnosis, assists in the differentiation of disease subtypes, guides biopsy when necessary, and provides prognostic and therapeutic insights essential for optimal patient care.

3- Imaging Patterns of Pulmonary Fibrosis on Chest CT

3-1. Usual Interstitial Pneumonia (UIP) Pattern

The UIP pattern is most strongly associated with IPF and may also be seen in connective tissue disease–associated ILD or chronic hypersensitivity pneumonitis. HRCT findings characteristic of UIP include basal and subpleural-predominant reticulation, honeycombing, and traction bronchiectasis, typically in the absence of significant ground-glass opacity (3, 6, 33). Honeycombing appears as clustered cystic airspaces measuring 3–10 mm in diameter with well-defined walls, most prominent in the posterior and basal regions (34). The fibrotic changes in UIP are classically posterior, peripheral, and lower-lobe predominant, with an anteroposterior gradient in advanced cases. The sparing of the immediate subpleural lung in some areas and the presence of lobular distortion are supportive of the diagnosis (35). A definite UIP pattern on HRCT is associated with poor prognosis and limited response to immunosuppressive therapies, emphasizing the importance of early recognition (36).

3-2. Nonspecific Interstitial Pneumonia (NSIP)

NSIP is the second most common fibrotic pattern and is frequently encountered in patients with CTD-ILD or idiopathic interstitial pneumonias. HRCT features include ground-glass opacity, fine reticulation, volume loss, and in some cases, traction bronchiectasis, with minimal or absent honeycombing (27, 37). NSIP typically shows a bilateral, symmetric, lower-lobe distribution, with subpleural sparing seen in many cases. The presence of a uniform appearance and lack of zonal heterogeneity helps distinguish it from UIP (38). Patients with NSIP generally have a more favorable prognosis than those with UIP, and the pattern may be more responsive to corticosteroids and immunomodulatory therapy (39).

3-3. Other Patterns: Organizing Pneumonia and Unclassifiable ILDs

Organizing pneumonia (OP), often seen in cryptogenic organizing pneumonia (COP) or secondary to infection, autoimmune disease, or drug exposure, may present with peripheral or peribronchial consolidations, reverse halo sign, and mild architectural distortion. Fibrotic progression is less common but may occur with chronicity (40, 41).

Unclassifiable patterns occur when imaging features overlap or are incomplete. These may show mixed features of fibrosis and inflammation, making diagnosis challenging. Multidisciplinary discussion is often required in such cases to reach a consensus based on clinical, radiologic, and, if available, histologic data (30, 42).

4- Prognostic Significance of CT Findings in Pulmonary Fibrosis

Chest HRCT is not only a diagnostic tool in pulmonary fibrosis but also serves as a valuable predictor of disease prognosis. Several qualitative and quantitative CT features have been identified as independent prognostic markers, correlating with survival, functional decline, and clinical progression. These imaging biomarkers, whether evaluated visually or through automated tools, contribute to patient risk stratification and therapeutic decision-making (43,44).

4-1. Extent of Fibrosis

The overall extent of fibrotic involvement on HRCT is among the most robust imaging predictors of mortality in fibrotic ILDs. Extensive fibrosis, defined by a higher percentage of lung involvement with reticulation, traction bronchiectasis, and honeycombing, is associated with more rapid

disease progression and reduced survival, particularly in IPF (9, 45). Visual scoring systems, such as the Kazerooni or Warrick scores, have been widely used in clinical and research settings to estimate disease burden and track changes over time (46).

4-2. Key Fibrotic Features: Honeycombing and Traction Bronchiectasis

Specific CT findings, particularly honeycombing and traction bronchiectasis, have been linked to unfavorable outcomes. Honeycombing, a hallmark of UIP, consistently portends a worse prognosis regardless of the underlying ILD subtype (6, 47). Similarly, the presence and extent of traction bronchiectasis reflect architectural distortion and fibrotic remodeling and are independently associated with reduced lung function and survival (48). In some scoring systems, such as the CT fibrosis score (CTFS), the degree of traction bronchiectasis contributes significantly to the overall fibrosis assessment (49).

4-3. Quantitative Imaging vs. Visual Assessment

While visual CT scoring remains the clinical standard, quantitative imaging techniques offer objective and reproducible assessments of fibrotic burden. Software tools can calculate the percentage of lung volume affected by fibrosis, ground-glass opacities, or honeycombing, providing a continuous variable that correlates with clinical outcomes. Studies have shown that quantitative metrics derived from CT, such as fibrosis extent and lung density histograms, correlate strongly with forced vital capacity (FVC) and DLCO (50-53).

4-4. Correlation with Pulmonary Function and Survival

Multiple studies have demonstrated that CT-derived fibrosis scores correlate with physiologic lung function indices. For example, greater fibrosis extent is associated with lower FVC and DLCO and predicts faster decline rates (54). In IPF, baseline HRCT fibrosis burden and its progression over time have been shown to predict survival more accurately than pulmonary function tests alone (55,56).

4-5. Emerging Tools: Radiomics and Artificial Intelligence

Recent advances in radiomics and artificial intelligence (AI) have introduced new methods for extracting prognostic information from HRCT. Radiomics involves the extraction of high-dimensional imaging features—such as texture, shape, and intensity—that are not visible to the naked eye. Preliminary studies suggest that radiomic signatures may differentiate progressive from stable disease and predict treatment response (57-59). Similarly, machine learning algorithms trained on large imaging datasets have demonstrated potential in predicting mortality, identifying subclinical progression, and enhancing risk stratification (60). Although still in early stages, these technologies may soon augment traditional imaging assessment and play a larger role in personalized disease management.

5. Emerging Trends and Future Directions

The evaluation of pulmonary fibrosis through chest CT has evolved significantly in recent years, driven by advances in imaging technology, machine learning applications, and growing consensus on standardized reporting. These developments aim to enhance diagnostic precision, reduce inter-observer variability, and improve prognostication and monitoring of fibrotic ILDs.

5-1. Machine Learning and Automated CT Analysis

AI, particularly deep learning and radiomics, has opened new frontiers in thoracic imaging. These techniques enable automated extraction of high-dimensional imaging features beyond the capabilities of human visual interpretation. In pulmonary fibrosis, AI-driven algorithms have been developed to quantify disease extent, identify radiologic patterns (e.g., UIP vs. NSIP), and predict clinical outcomes (60, 61). Studies have shown that AI-based CT analysis may outperform traditional visual scoring in assessing fibrosis progression and forecasting mortality risk (51, 62). Moreover,

such tools may facilitate earlier detection of subtle fibrotic changes in at-risk populations or preclinical stages of the disease.

5-2. Standardization in Imaging Interpretation

Efforts to standardiz CT interpretation have gained momentum, aiming to improve diagnostic consistency across institutions. The Fleischner Society has published key guidelines that provide structured frameworks for recognizing and classifying CT patterns of pulmonary fibrosis, particularly UIP and probable UIP (6, 63). These guidelines enhance the reproducibility of CT-based diagnoses and support multidisciplinary team discussions, which are critical for accurate classification and treatment planning. Ongoing initiatives are also exploring the integration of structured reporting templates and AI-assisted decision support into clinical workflows to further reduce variability (64,65).

5-3. Research Gaps and Future Directions

Despite significant advances, several limitations persist in the imaging-based assessment of pulmonary fibrosis. A major challenge is the overlap in CT features among different ILD subtypes, which can lead to diagnostic uncertainty, particularly in cases without histopathologic correlation. Additionally, while quantitative imaging shows promise, widespread clinical adoption is limited by the need for validation, standardization of analysis platforms, and integration into existing systems (57,66,67).

Limitations

Future studies should focus on large-scale validation of AI models, development of prognostic imaging biomarkers, and correlation of imaging data with molecular and genetic signatures to better understand disease heterogeneity. There is also a need for longitudinal studies to evaluate how AI-derived imaging metrics evolve with treatment and how they may inform therapeutic decisions, especially in the era of anti-fibrotic agents and personalized medicine.

While this narrative review provides a synthesized account of key chest CT imaging features in pulmonary fibrosis and their prognostic implications, several limitations must be acknowledged. As a narrative rather than a systematic review, the study selection and interpretation process involved a degree of subjectivity. Despite a comprehensive search strategy across multiple databases, the absence of predefined inclusion criteria or quantitative analysis may have introduced selection bias.

Additionally, the heterogeneity of the existing literature—spanning various ILD subtypes, imaging methodologies, and outcome measures—limits the generalizability of some findings. For instance, differences in CT acquisition protocols, visual scoring systems, and population characteristics may affect the comparability of results across studies. Furthermore, many of the included studies were retrospective in design or had small sample sizes, which could affect the strength of evidence supporting certain imaging biomarkers.

The emerging use of artificial intelligence and quantitative imaging tools presents exciting opportunities; however, these technologies remain largely investigational. Their prognostic value, while promising, has not yet been validated in large, multicenter, prospective studies. Therefore, caution is warranted when extrapolating their results into routine clinical practice.

Finally, potential publication bias may have influenced the available data, as studies with positive findings tend to be more frequently published. These limitations highlight the need for more standardized, high-quality research to strengthen the clinical utility of CT imaging in pulmonary fibrosis.

Conclusion

HRCT has become a cornerstone in the evaluation of pulmonary fibrosis, offering detailed visualization of lung parenchymal abnormalities that are critical for diagnosis, classification, and prognosis. The recognition of specific imaging patterns, such as UIP and NSIP, provides essential insights into the underlying disease process and can significantly influence clinical management and therapeutic decision-making.

Prognostically, CT features such as the extent of fibrosis, presence of honeycombing, and traction bronchiectasis have consistently been associated with adverse outcomes. Quantitative imaging approaches and emerging artificial intelligence tools are poised to enhance objectivity in disease assessment, although further validation is needed before widespread clinical adoption.

Despite limitations inherent in a narrative approach, this review highlights the evolving and multifaceted role of CT in the management of fibrotic ILDs. Continued refinement of imaging techniques, integration of advanced computational tools, and adherence to standardized interpretation guidelines will be key in optimizing diagnostic accuracy and improving patient outcomes.

Declaration

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