The role of radiological imaging in the management of severe and difficult-to-treat asthma

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Shareable abstract (@ERSpublications)
Imaging plays a vital role in asthma diagnosis and detection or exclusion of comorbidities. Further research is required to standardise the application of imaging in asthma and allied diseases. https://bit.ly/3WIWSN9

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Abstract

Radiological imaging has proven to be a useful tool in the assessment of asthma, its comorbidities and potential complications. Characteristic chest radiograph and computed tomography scan findings can be seen in asthma and in other conditions that can coexist with or be misdiagnosed as asthma, including chronic rhinosinusitis, inducible laryngeal obstruction, excessive dynamic airway collapse, tracheobronchomalacia, concomitant COPD, bronchiectasis, allergic bronchopulmonary aspergillosis, eosinophilic granulomatosis with polyangiitis, and eosinophilic pneumonia. The identification of the characteristic radiological findings of these conditions is often essential in making the correct diagnosis and provision of appropriate management and treatment. Furthermore, radiological imaging modalities can be used to monitor response to therapy.

Educational aim

- To discuss the role of imaging modalities in difficult-to-treat asthma management, especially the evaluation of asthma severity and the identification of comorbidities and complications.

Introduction

Asthma is one of the most common chronic diseases worldwide in terms of its prevalence, symptom severity and risk of premature death [1]. Uncontrolled asthma is characterised by poor symptom control and/or frequent exacerbations. The Global Initiative for Asthma (GINA) defines difficult-to-treat asthma (DTA) as asthma that is uncontrolled despite prescribing medium- or high-dose inhaled corticosteroids (ICS) with a second controller (usually a long-acting β-agonist (LABA)) or with maintenance oral corticosteroids (OCS), or that requires high-dose treatment to maintain good symptom control and reduce the risk of exacerbations [2]. It is important to distinguish asthma that is difficult to treat due to comorbidities from true severe asthma, hence the need for appropriate investigations in asthma management [3]. Comorbidities in DTA are wide ranging and include chronic rhinosinus diseases, COPD, bronchiectasis, allergic bronchopulmonary aspergillosis (ABPA), eosinophilic granulomatosis with polyangiitis (EGPA), eosinophilic pneumonia, inducible laryngeal obstruction (ILO), and excessive dynamic airway collapse (EDAC) [4]. Mimickers of asthma conditions, such as ILO and EDAC, can coexist with asthma or be the exclusive main diagnosis that drives symptoms [5]. Thus, in the severe asthma clinic the role of imaging in the patient assessment algorithm has increasingly being regarded as pivotal in making the correct diagnosis and in some aspects also in the assessment and monitoring of treatment response.

In this article, we review the role of imaging in the management of patients presenting with DTA and associated comorbidities.

Asthma

The diagnosis of asthma is made based on characteristic symptom patterns and evidence of variable expiratory airflow limitation [6]. The plain chest radiograph is almost always normal in the absence of comorbidities and concurrent disease. It can be helpful in acute asthma exacerbations to exclude differential diagnoses like infection, pneumothorax and pneumomediastinum [7]. The most common abnormal finding is bronchial wall thickening (BWT) followed by hyperinflation [8].

A high-resolution computed tomography (HRCT) scan of the thorax is commonly performed in patients with DTA as a noninvasive assessment of the airway tree, lung parenchyma, ventilation patterns and pulmonary vasculature [7, 9, 10]. Persistent airway inflammation in asthma induces airway remodelling changes in the form of airway wall oedema, subepithelial matrix protein deposition and fibrosis, hypertrophy of the smooth muscle cells, mucus gland hyperplasia, and overexpression of angiogenic factors [11, 12]. The HRCT findings of airway remodelling include BWT, mucus plugging, bronchiectasis and air-trapping (mosaic attenuation) [7, 8]. The degree of BWT and air-trapping correlates with the severity of asthma [8, 12].

In a UK study of 290 patients with DTA, the main observed HRCT abnormalities were BWT (76.1%), bronchiectasis (49.4%), ground-glass changes (34.7%), mucus plugging (28.1%), air-trapping (29.2%), central bronchiectasis suggestive of ABPA (7.2%), emphysema (5.5%) and eosinophilic pneumonia (<1%) [13]. Similarly, another UK-based study of 185 patients with DTA reported radiological findings of BWT in 62% of cases, bronchiectasis in 40% and emphysema in 8% [14]. The DTA patients included in the latter study were those who had undergone HRCT scan and they were older, had longer duration of symptoms, lower lung function, and had more neutrophilic airway inflammation than those who attended the same clinic but did not have HRCT. The latter study also noted that non-radiological assessments such as lung function failed to reliably predict important bronchial wall changes [14].

Multidetector lung computed tomography (CT) using a bronchopulmonary segment-based scoring system to quantify mucus plugs (figure 1), identified airways mucus plugs in 58% of the US- Severe Asthma Research Program (SARP)-3 cohort. Mucus plugs were predominantly seen in the subsegmental airways in the absence of bronchial dilatation. Participants with high mucus plug scores had more severe airway obstruction and increased sputum eosinophilia, suggesting that mucus plugs identify a persistent asthma phenotype and severe airflow obstruction [15]. The airway mucus score is a noninvasive way to assess

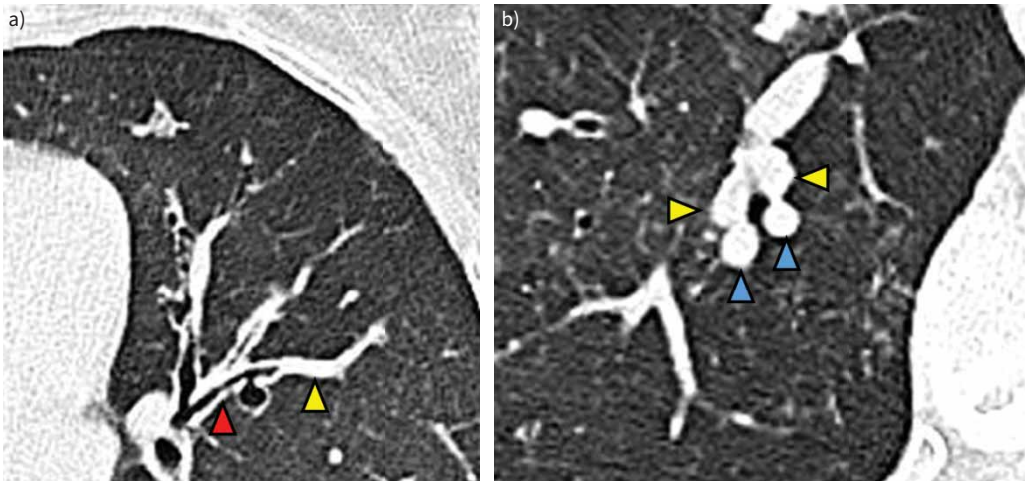

FIGURE 1 Demonstration of mucus plug in the airways of a patients with severe eosinophilic asthma detected on high-resolution computed tomography (CT). a) Mucus plug (yellow arrows) seen as tubular opacification in the longitudinal view of branching airway associated with peribronchial wall thickening (red arrow), and b) in the cross-section view, in which the mucus plugged airway (yellow arrows) is seen in conjunction with the adjacent blood vessels (blue arrows). A CT-based mucus score was developed to quantify the mucus burden in asthma and other airway diseases and relate that to clinical outcomes [15]. In this a mucus plug was defined as complete occlusion of a bronchopulmonary segment. Individual bronchopulmonary segments were assessed and scored for presence of mucus plugs and the segment-scores were summed to provide an overall mucus score [15].

airway dysfunction and may become a useful tool that can be used both clinically and in research, such as to assess treatment responses in asthma clinical trials [16].

Chronic rhinosinusitis

CT of the paranasal sinuses may help identify chronic rhinosinusitis (CRS) (figure 2), with or without nasal polyps (CRSwNP and CRSsNP, respectively), which in the presence of severe asthma may help decide on the choice of biologic therapy [6]. CRSwNP is found in around 40–60% of severe eosinophilic asthma, indicating type-2-predominant inflammation with high levels of interleukin-5 (IL-5) and eosinophilic inflammation [17–21]. Eosinophilic asthma with CRSwNP is a treatable trait that responds well to biologic therapy manifesting in a reduction in asthma exacerbations, use of OCS and improvement in asthma control and asthma-related quality of life [17].

Inducible laryngeal obstruction

ILO (formerly known as vocal cord dysfunction (VCD)) is a common asthma mimic and coexists with asthma. In a meta-analysis, 25% of adult asthma patients were reported to have ILO [22]. ILO is characterised by paradoxical vocal cord adduction during inspiration and/or expiration that is transient and reversible, leading to symptoms of breathlessness and wheeze. It shares common triggers with asthma such as rhinosinus disease, gastro-oesophageal reflux and psychological factors. Classically, ILO symptoms in the form of wheeze, dyspnoea, throat tightness, chest tightness and cough appear abruptly and resolve quickly and tend not to respond well to asthma medication [23, 24]. The inappropriate laryngeal closure at the glottic and/or supraglottic level during an ILO attack leads to dynamic airflow obstruction and causes breathing difficulties [25, 26].

The “gold standard” investigation for confirmation of ILO is flexible laryngoscopy, demonstrating >50% of laryngeal closure is due to paradoxical vocal cord movement [23]. If necessary, laryngoscopy is performed in the presence of a typical trigger (*e.g.* exercise). Dynamic volume CT sequencing of the neck can assess laryngeal movement during respiration and has been used to identify possible laryngeal dysfunction in

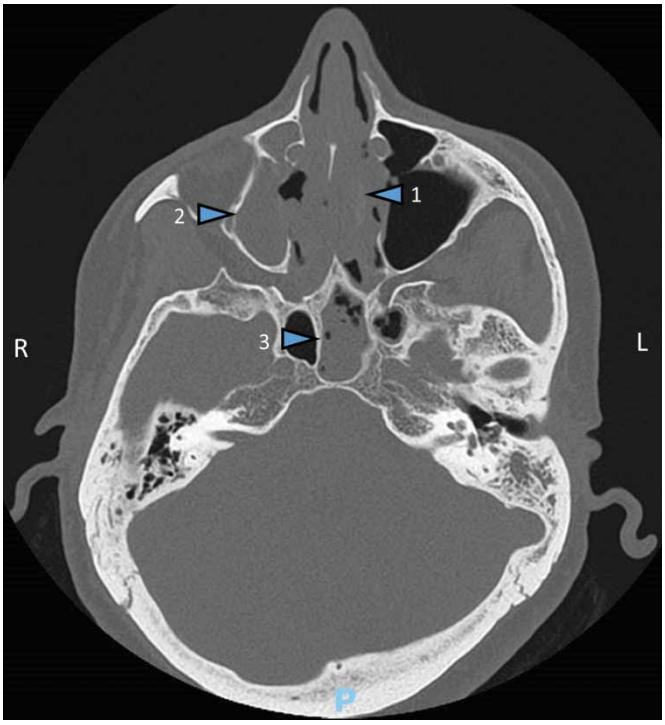

FIGURE 2 Paranasal sinus computed tomography scan in a patient with severe eosinophilic asthma and symptoms of blocked nose, postnasal drip and recurrent paranasal rhinosinusitis. The scan revealed bilateral nasal polyps present in the nasal cavity obscuring the osteomeatal complex regions (arrow 1), alongside complete opacification of right maxillary sinus (arrow 2) and near complete opacification of the left sphenoid sinus (arrow 3).

patients with DTA [24]. Koh *et al.* [27] recently compared laryngoscopy with CT imaging of the larynx and reported that low-dose CT imaging of the larynx detects ILO with a negative predictive value between 80% and 90%, indicating the potential utility of CT-larynx in ILO diagnosis. Limitations to the use of CT scans in the diagnosis of ILO include the absence of documentation of a symptomatic spontaneous or provoked episode during testing, need for supine positioning and brief data acquisition window due to concerns about radiation exposure, although the radiation dose exposure can be small [23].

Excessive dynamic airway collapse and tracheobronchomalacia

Both EDAC and tracheobronchomalacia (TBM) cause an exaggerated tracheobronchial narrowing during expiration, also termed expiratory central airway collapse (ECAC) [28]. ECAC presents with cough, breathlessness and recurrent chest infections and is often misdiagnosed as asthma [5]. EDAC is associated with obstructive airway diseases such as COPD and asthma [29]. EDAC is characterised by an exaggerated inward bulging of the posterior tracheal membrane with normal configuration of tracheal cartilage (figure 3). TBM is characterised by abnormality of the tracheal and/or bronchial cartilage resulting in expiratory flow limitation, including tracheomalacia (limited to the trachea), bronchomalacia (limited to the bronchi), or TBM (involving the trachea and bronchi) [28]. EDAC is more common than TBM and both are more prevalent in females, older age and severe asthma. Up to 70% and 19% of patients from a severe asthma cohort were reported to have EDAC and TBM, respectively [30].

The physiological impact of the ECAC on airflow and the overall functional status requires careful assessment for accurate diagnosis and treatment. A multidetector helical CT scan can be used to image the central airways during both the dynamic expiratory phase and end-inspiratory phase, and a ⩾70% reduction in large airway calibre appears to be the most widely used diagnostic criterion in clinical practice [28].

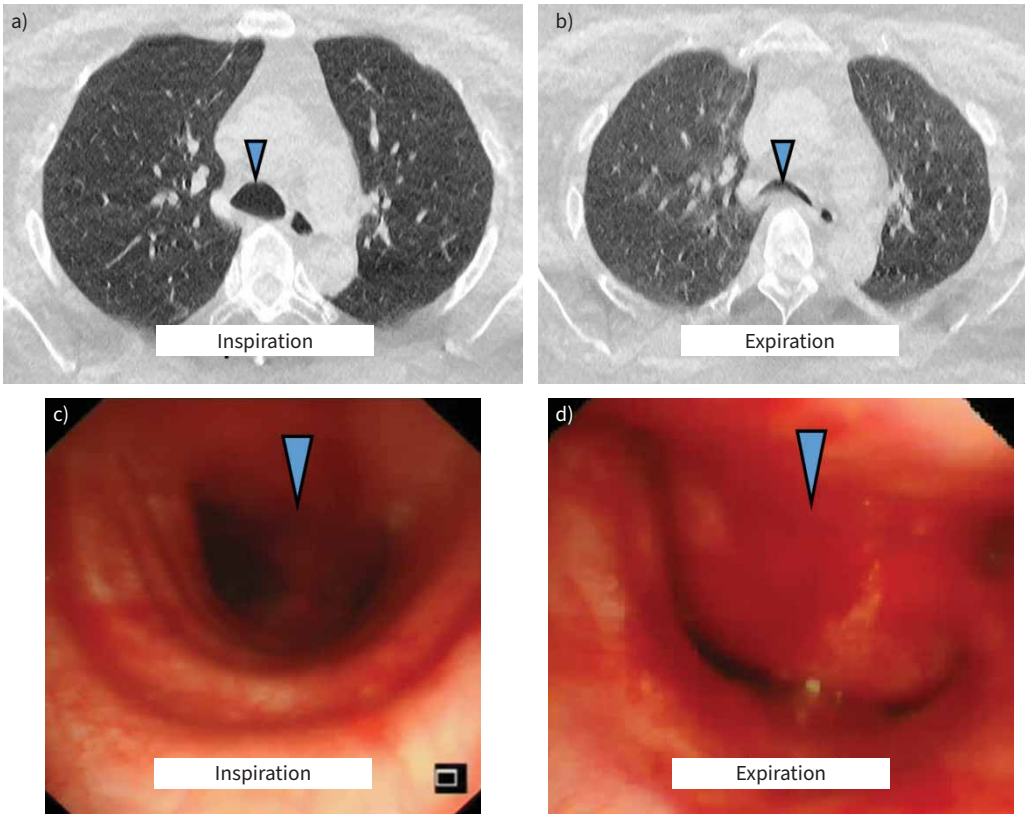

FIGURE 3 A case of excessive dynamic airway collapse (EDAC) in middle-aged female who presented with exertional breathlessness and wheeze in conjunction with difficult expectoration and intractable barking cough. The large airway at the lower trachea and carina was open on inspiration (arrows, a) computed tomography (CT) scan, c) bronchoscopy), and narrowed significantly on expiration (arrows, b) CT scan, d) bronchoscopy) in keeping with EDAC diagnosis. The magnitude of large airways collapse on expiration (tidal breathing) required to meet EDAC diagnosis criteria is not agreed and ranges from 50% to 90%, with some clinicians using the 70% cut-off level in combination with suggestive clinical features to make the diagnosis.

Flexible bronchoscopy is considered by many clinicians to be the gold standard approach to the diagnosis of large airway collapse as it allows real-time assessment of the dynamic airway properties and repeated and sequential assessments during different manoeuvres [31].

Concomitant COPD

Asthma and COPD are regarded as separate clinical conditions; however, they are both heterogenous with similar symptoms and diagnostic criteria. A significant number of patients have features of both conditions and tend to do clinically worse than those with asthma or COPD alone as a diagnosis [6, 32, 33]. The presence of radiologically detected emphysema is considered when differentiating asthma from COPD [6]. Marked hyperinflation is most often seen on plain chest radiographs in emphysema [8]. CT imaging has a greater sensitivity and specificity than chest radiography in determining the type, extent and distribution of emphysema (figure 4) [34].

Bronchiectasis

Bronchiectasis is commonly found in asthma, particularly those with uncontrolled, severe and corticosteroid-dependent asthma [35]. It is more frequent in older asthmatic patients and those with a smoking history [3]. The cause and effect relationship between bronchiectasis and asthma is still debatable [36]. Several hypotheses have been postulated including neutrophilic airway inflammation, protease–antiprotease imbalance and recurrent airway infections [3, 37, 38]. Coexistent bronchiectasis is associated with severe airflow obstruction leading to a higher rate of exacerbations and uncontrolled asthma [3, 39]. Bronchiectasis may also be found in asthma patients with ABPA.

Chest radiography has limited sensitivity and specificity in diagnosing bronchiectasis especially in cases of mild disease [40]. HRCT is the gold standard for diagnosis of bronchiectasis [41]. Bronchiectasis is defined by bronchial dilatation suggested by at least one of the following: broncho–arterial ratio >1 (internal airway lumen *versus* adjacent pulmonary artery), lack of tapering and airway visibility within 1 cm of the costal pleural surface or touching mediastinal pleura. In addition, BWT, mucus impaction and mosaic perfusion/air-trapping on expiratory HRCT are commonly associated with bronchiectasis [40]. Other CT findings include mucus plugging, “tree-in-bud” nodularity, a waxing and waning pattern to the nodules, and cystic changes and cavitation in advanced bronchiectasis [41]. Studies have shown that cylindrical bronchiectasis is the predominant pattern of bronchiectasis in asthma [39, 42].

Fungal asthma

Severe asthma with fungal sensitisation (SAFS) is a relatively common condition in patients with DTA and has been reported to affect up to 36.4% of patients [43]. SAFS represents sensitisation to any fungal antigens in patients with severe asthma without the presence of fungal-related lung diseases. In contrast, bronchopulmonary aspergillosis is a group of pulmonary disorders caused by *Aspergillus* species and includes ABPA, aspergilloma, chronic necrotising aspergillosis, and invasive pulmonary aspergillosis.

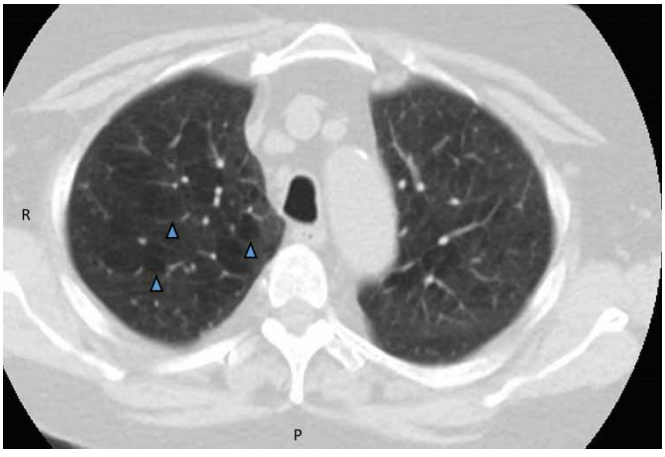

FIGURE 4 Computed tomography (CT) demonstration of concomitant emphysema in a patient presenting with difficult-to-treat asthma. In this case, severe asthma was diagnosed on the basis of a significant post-bronchodilator increase in forced expiratory volume in 1 s of 250 mL (31%) and blood eosinophilia in an ex-smoker with a history of 40 pack-years of tobacco smoked. The figure shows centrilobular emphysema which was widespread but with more prominent upper lobes distribution (blue arrows).

In the context of DTA, SAFS and ABPA are the main conditions encountered. ABPA is caused by a hypersensitivity to *Aspergillus fumigatus* through a type I immunoglobulin E (IgE) and type III immunoglobulin G (IgG) immune responses [44]. ABPA has been classified as serologic ABPA (ABPA-S) and ABPA with central bronchiectasis (ABPA-CB), depending on the absence or presence of central bronchiectasis, respectively [45]. In DTA, ABPA is encountered in a significant minority (7.3%) of cases [43]. ABPA is often refractory to treatment and represents a significant challenge to the treating physician particularly in advanced disease cases with structural lung changes [46]. The ABPA diagnostic criteria proposed by the International Society for Human and Animal Mycology includes predisposing asthma or cystic fibrosis, immediate cutaneous hypersensitivity to *Aspergillus* antigen or elevated serum specific IgE levels against *A. fumigatus*, elevated total IgE levels, and at least two out of three minor criteria including presence of precipitating (IgG) antibodies to *A. fumigatus*, radiographic features in the lungs consistent with ABPA, or peripheral blood eosinophilia greater than 500 cells per µL in corticosteroid-naïve patients [47–49]. ABPA diagnosis is often delayed or missed with an ensuing delay in treatment that can lead to disease progression and worsened airway and parenchymal lung damage such as bronchiectasis [45].

The chest radiograph in ABPA may appear normal, however there may be characteristic fleeting opacities found during ABPA exacerbations, and fixed abnormalities such as consolidation seen in the advanced stages. Findings of tramline shadows, finger-in-glove opacities and consolidation represent mucus impaction of bronchi and bronchiectatic cavities [50]. Fibrosis and collapse may indicate the development of chronic pulmonary aspergillosis in advanced stages [51].

HRCT is the imaging modality of choice in ABPA [50]. Central with predominant upper and middle lung lobes distribution of bronchiectasis is commonly observed in ABPA [35]. Other pathognomonic radiological findings in ABPA are high-attenuation mucus, centrilobular nodules, tree-in-bud opacities and mosaic attenuation (figure 5) [50]. ABPA can also present without characteristic radiological features in ABPA-S [44].

Eosinophilic granulomatosis with polyangiitis

EGPA, formerly known as Churg–Strauss syndrome, is a rare small-vessel vasculitis that often occurs in patients with asthma with blood and tissue eosinophilia. EGPA is histologically characterised by tissue eosinophilia, necrotising vasculitis and eosinophil-rich granulomatous inflammation [52, 53]. Over 90% of patients with EGPA have coexistent asthma, which is usually of adult onset, severe and corticosteroid dependent, tends to progressively worsen and precedes the onset of systemic disease by several years [54]. The natural history of EGPA usually follows three stages: initially asthma and rhinitis, then tissue eosinophilia (including eosinophilic pneumonia), and finally extrapulmonary eosinophilic disease with vasculitis [54–56]. In addition to asthma, EGPA patients characteristically have upper airway symptoms and general symptoms, such as arthralgia, myalgia, malaise, fever and weight loss [55].

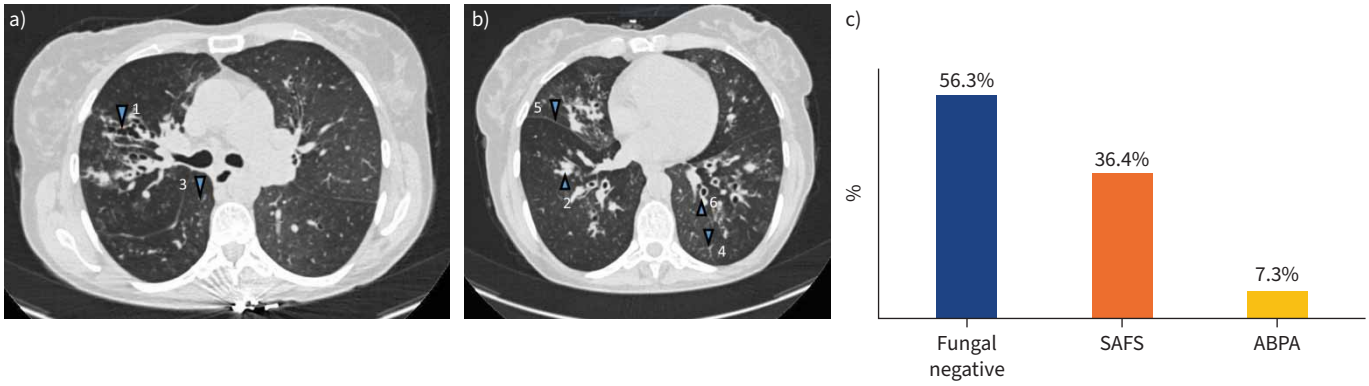

FIGURE 5 a, b) Sections of high-resolution computed tomography scan of thorax of patients with allergic bronchopulmonary aspergillosis (ABPA) demonstrating extensive cystic bronchiectasis (1), mucus plugging (2), centrilobular nodules (3), tree in-bud opacities (4), mosaic attenuation (5) and bronchial wall thickening (6). The radiological features were compatible with the laboratory results for this patient in which total serum immunoglobulin E (IgE) was >5000 kU·L^{-1} (normal <120), specific serum IgE to *Aspergillus* was 52.9 kUA·L^{-1} (normal <0.34), and serum specific IgG to *Aspergillus* was 268 mg·L^{-1} (normal <39.99). c) In a review of 254 patients with severe asthma, the proportion with severe asthma and fungal sensitisation (SAFS) was 93 out of 254 (36.4%), while 18 out of 247 (7.3%) met the ABPA criteria [43].

Lung infiltrates are the most typical manifestation of EGPA on chest radiography and appear as peripheral patchy consolidations with a migratory course [57]. Common EGPA findings on HRCT are similar to those of severe asthma and include BWT, air-trapping, bronchial mucus plugging and bronchiectasis. Other findings include tree-in-bud opacities, ground-glass opacities and consolidation in either a patchy or a predominantly peripheral distribution, increased small vascular markings, interlobular septal thickening and atelectasis [58]. HRCT can differentiate EGPA from asthma. In one study, the radiological grading-score of EGPA cases was significantly higher than that of severe asthma, with diffuse ground-glass opacities being a significant differentiating feature that were seen in 74% of EGPA and 18% of severe asthma patients ($p<0.001$) [58].

Eosinophilic pneumonia

Eosinophilic pneumonia is usually idiopathic in origin and can be acute (<5 days in duration) or chronic [53]. Acute eosinophilic pneumonia (AEP) tends to present in the third decade of life with fever, cough, myalgia, dyspnoea and type 1 respiratory failure that often requires assisted ventilation. Chest radiographs tend to demonstrate widespread alveolar and interstitial infiltrates. HRCT features of AEP include peripherally distributed consolidation and ground-glass opacification, smooth interlobular septal thickening, bronchovascular bundle thickening with presence of small pleural effusions in the absence of cardiomegaly. The blood eosinophil level is often normal in AEP but typically there is bronchoalveolar fluid eosinophilia of >25% in the absence of parasitic, fungal or other infections and lack of history of drug hypersensitivity [59–61].

Chronic eosinophilic pneumonia (CEP) is rare and tends to present in middle age. Patients often have a prior history of asthma and atopy including eczema, nasal polyposis and urticaria [53]. The clinical course tends to be progressive or subacute with symptoms of breathlessness and cough over several weeks or months before a diagnosis is made [53, 62]. Patients usually have raised blood eosinophils with abnormal chest radiography demonstrating pulmonary infiltrates [62, 63]. HRCT features of CEP include patchy bilateral air-space opacities and septal thickening in the upper zone that can adopt fleeting picture over time and moderate hilar and mediastinal lymphadenopathy (figure 6) [62, 64]. CEP is an idiopathic condition and therefore secondary

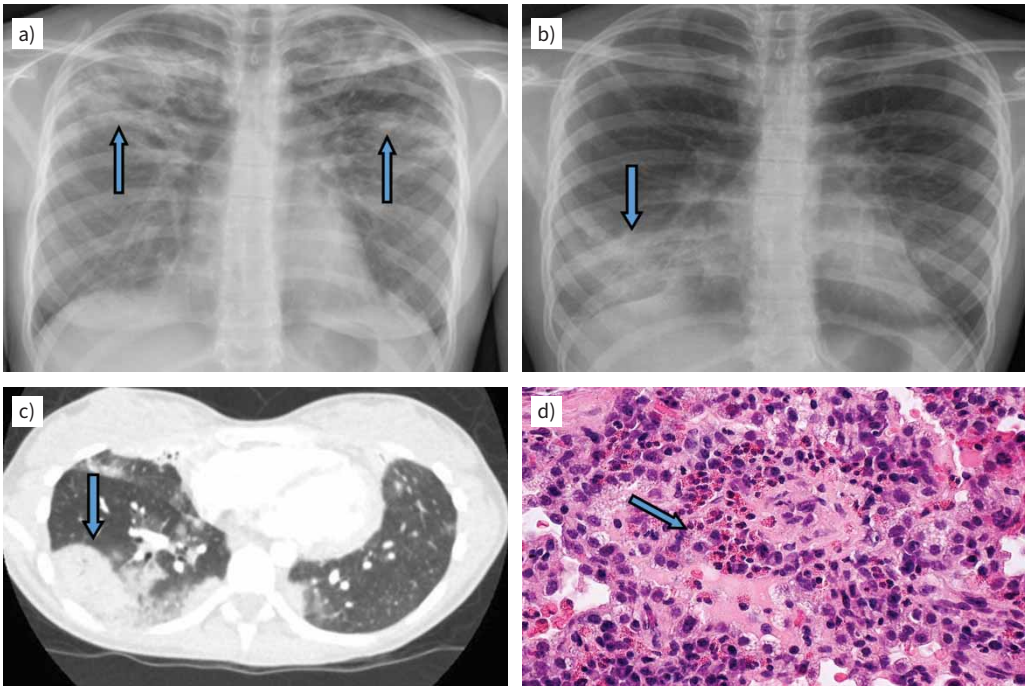

FIGURE 6 A young female presented with prodromal symptoms of cough, fever and malaise. Her peripheral blood eosinophil level was 3400 cells per μL and C-reactive protein 163 mg·L^{-1}. a) The chest radiograph at the first presentation revealed patchy upper zone pulmonary infiltrates which resolved 3 weeks afterwards; however, at the same time a right lower lobe consolidation was observed on b) the chest radiograph and c) computed tomography (CT) scan of the thorax. There was no response to standard antibiotic treatment for pneumonia and a *Mycobacterium tuberculosis* screen was negative. d) A CT-guided biopsy was performed and revealed accumulation of numerous eosinophils in the alveolar spaces and interstitium in keeping with eosinophilic pneumonia. Arrows point to the relevant abnormalities.

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Table 1 Summary of salient radiological features and their prevalence in difficult-to-treat asthma (DTA) and related comorbidities

Disease	Radiological features	Prevalence and significance	Radiological modality/added value	Notes
Asthma [14]	Air-trapping Mucus plugging BWT Ground-glass changes	29% 28–58% 76% 35% (prevalence rates in DTA)	HRCT These features are not reliably predicted from other investigation	Mucus plugging and BWT correlated with airflow limitation
Bronchiectasis [3]	Bronchial dilatation Lack of airway tapering Mucus plugging Air-trapping Radiologically visible airway in the lung perimeter	Bronchiectasis was reported to be present in up to 50% of DTA cohorts	HRCT Diagnostic investigation of choice to establish the diagnosis and extent	HRCT is required for bronchiectasis diagnosis and investigation of associated comorbidities
COPD [34]	Share common features with asthma *e.g.* BWT and mucus plugging Emphysema	Reported in up to 8% of severe asthma cases	HRCT Informs on the presence of emphysema and its extent	Coexistence of asthma and COPD is associated with worsened clinical outcome
CRS [68]	CRS without nasal polyps (CRSsNP) CRS- with nasal polyps (CRSwNP)	40–60% of severe asthma 14.9–45% of severe asthma	CT scan of paranasal sinuses For diagnosis and disease extent assessment	CRS worsens severe asthma outcomes and may predict response to biologic treatment
ILO [24]	Transient and reversible laryngeal obstruction	Present in up to 30% of DTA	Low-dose dynamic CT imaging of larynx may detect ILO	Gold standard is laryngoscopy with or without provocation (Role of CT is still experimental)
EDAC, TBM [30]	EDAC: Exaggerated inward bulging of the posterior trachea TBM: abnormality of the airway cartilage	In up to 70% of DTA 19% in DTA	Dynamic HRCT inspiratory/expiratory Expiratory large airway calibre reduction of ⩾70% for diagnosis	Dynamic HRCT is required for EDAC/TBM investigation followed by dynamic bronchoscopy for diagnostic evaluation if required
ABPA [45]	Serologic (ABPA-S) (no radiological abnormality) With central bronchiectasis (ABPA-CB) (central bronchiectasis, high-attenuation mucus, centrilobular nodules, tree-in-bud opacities)	4% 12% (prevalence rates in severe asthma)	HRCT Essential for the investigation of ABPA	HRCT aids in diagnosis confirmation and provides information on disease extent and severity
EGPA [58]	BWT Air-trapping Tree-in-bud opacities Bronchial mucus plugging, bronchiectasis Ground-glass opacities (GGOs) and consolidation patchy/peripheral Increased small vascular markings	Rare in severe asthma (~3.5%)	HRCT and CT with pulmonary angiogram EGPA shares many of the severe asthma features, but they are more severe in EGPA with significantly more ground-glass changes	Other non-airway features, such as increased small vascular markings and interlobular thickening, can be seen in EGPA cases
CEP [59–61]	Patchy bilateral air-space opacities and septal thickening in the upper zone that can adopt fleeting picture overtime Moderate hilar and mediastinal lymphadenopathy	Prevalence in severe asthma is not known (likely <1%)	HRCT Essential diagnostic test to aid in eosinophilic pneumonia diagnosis and detection of causes or other diseases	CEP diagnosis requires exclusion of other causes of eosinophilic syndromes (*e.g.* tropical pulmonary eosinophilia)
HES [66, 67]	Spontaneously clearing air space shadowing in early disease Diffuse parenchymal pulmonary infiltrate in more severe cases	Not known in severe asthma 0.036 per 100 000 of the general population	CT scan with contrast forms part of the diagnostic work-up of HES	Cardiovascular involvement and thromboembolic disease are significant complications that require CT scan with contrast and echocardiography

CRS: chronic rhinosinusitis; ILO: inducible laryngeal obstruction; EDAC: excessive dynamic airway collapse; TBM: tracheobronchomalacia; ABPA: allergic bronchopulmonary aspergillosis; EGPA: eosinophilic granulomatosis with polyangiitis; CEP: chronic eosinophilic pneumonia; HES: hypereosinophilic syndrome; BWT: bronchial wall thickening; HRCT: high-resolution computed tomography.

causes of eosinophilic pneumonias require exclusion through careful clinical assessment. The other main causes include tropical eosinophilia, use of illicit substances, ABPA, EGPA, and hypereosinophilic syndrome (HES) [62, 65]. HES is associated with marked blood eosinophilia (>1500 cells·mm^{-3}) for more than 6 months with the absence of other causes of eosinophilia and in presence of evidence of end-organ damage due to eosinophilia [66, 67]. Pulmonary involvement is encountered in 40% of HES patients leading to cough and airflow limitation with an obstructive and/or restrictive lung function in the presence of pulmonary fibrosis. Radiological features can range from spontaneously clearing air space shadowing in early disease to diffuse parenchymal pulmonary infiltrate in more severe cases [67]. Other radiological features could reflect cardiac decompensation due to cardiovascular involvement and thromb-embolic diseases which are important causes of morbidity and mortality in HES [66, 67].

Conclusion

Imaging plays an essential role in the diagnosis and management of DTA, and its related comorbidities and complications. Given the presence of overlapping radiological features, accurate diagnosis relies on the combined consideration of the clinical presentation, laboratory findings and imaging. Radiological imaging can also monitor disease course and treatment response. Access to radiological imaging such as chest radiography and HRCT and an expert chest radiologist will enhance the diagnostic accuracy within a DTA clinic (table 1). Research is warranted to further define the role of radiological imaging in the management of DTA such as in establishing more clearly the clinical indication to conduct CT of thorax, which radiological modality to conduct, and to standardise CT scan settings and reporting, for example, the use of a dynamic multidetector helical CT in EDAC/TBM or the use of a sensitive scoring system to evaluate mucus impaction in severe asthma.

Key points

- Radiological imaging is essential in investigating and treating DTA, its comorbidities and complications.

Self-evaluation questions

1. What are the common CT scan abnormalities in patients with DTA?
2. What is the preferred imaging modality for diagnosing EGPA and what are its distinguishing features?
3. ILO can be definitively diagnosed with CT imaging of the larynx. Is this statement true or false?
4. What are the diagnostic criteria for ABPA?
5. What imaging modalities can be used in the diagnosis of EDAC and TBM, and what is the characteristic feature?

Conflict of interest: None declared.

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Suggested answers

1. Bronchial wall thickening, bronchiectasis, ground-glass changes, mucus plugging, and air-trapping.
2. High-resolution CT with distinguishing features that include bronchial wall thickening, air-trapping, and ground-glass opacities, often in a peripheral distribution.
3. False. While CT imaging of the larynx can assist in diagnosing ILO, the gold standard for confirmation is flexible laryngoscopy demonstrating >50% laryngeal closure.
4. Predisposing asthma, immediate hypersensitivity to *Aspergillus* antigen or elevated specific IgE levels against *Aspergillus*, elevated total IgE levels, and at least two minor criteria such as the presence of IgG antibodies to *Aspergillus*, radiographic lung features consistent with ABPA, or peripheral blood eosinophilia.
5. Dynamic multidetector helical CT scan and flexible bronchoscopy, a >70% reduction in large airway calibre.