High Resolution CT in Obstructive and Airways Lung Disease

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The recent development of high-resolution CT (HRCT) and dynamic CT techniques have signiflcantly improved our ability to image morphologic abnormalities associated with airways diseases and chronic airflow obstruction. This disparate group of diseases can be associated with the presence of emphysema, cystic abnormalities, large airways abnormalities, small airways abnormalities, and findings of abnormal lung perfusion or air-trapping as shown on HRCT.[1]

EMPHYSEMA

Emphysema is characterized by "permanent abnormal enlargement of airspaces distal to the terminal bronchiole, accompanied by the destruction of their walls".[2] Emphysema is usually classified into three main subtypes, based on the predominant anatomic location of the areas of lung destruction; these 3 types are 1) centrilobular, 2) panlobular, and 3) paraseptal. In their early stages, these three forms of emphysema can be distinguished morphologically using HRCT. However, as they becomes more extensive, distinction between them becomes difficult or impossible, both radiographically and pathologically.

Centrilobular emphysema is most common; it usually results from cigarette smoking. Centrilobular emphysema predominantly affects respiratory bronchioles in the central portions of pulmonary acini, and therefore predominates in a centrilobular location.[2] It is most severe in the upper lung zones. Centrilobular emphysema of mild to moderate degree is characterizecl pathologically and on HRCT by the presence of small, round areas of low attenuation, several mm in diameter, grouped near the centers of secondary puimonary lobules, and lacking visible walls in many cases[3-5] Although the centrilobular location of lucencies cannot always be appreciated on HRCT, the presence of multiple, scattered, small areas of emphysema is diagnostic.

Panlobular emphysema is classically associated with alpha- l-protease inhibitor (alpha- 1antitrypsin) deficiency, although it may also be seen without protease deficiency in smokers, in the elderly, and distal to bronchial and bronchiolar obliteration.[2] Panlobular emphysema is characterized by uniform destruction of the pulmonary lobule, leading to large areas of abnormally low attenuation which are most easily appreciated as a diffuse "simplification" c.f lung structure.[3,6] It is almost always most severe in the lower lobes. In severe panlobular emphysema, the characteristic HRCT appearance is that of decreased lung attenuation, with few visible pulmonary vessels in the abnormal regions; bullae or cysts are characteristically absent. Mild and even moderately severe panlobular emphysema can be very subtle and difficult to detect.[7]

Paraseptal emphysema is charactenzed by involvement of the distal part of the secondary lobule and is therefore most striking in a subpleural location. It may be isolated or seen in combination with centrilobular emphysema. It is often asymptomatic, but can be associated with spontaneous pneumothorax in young adults.[2] The bullae or air cysts which are commonly seen in patients with paraseptal emphysema have visible walls, but the walls are very thin. Even mild paraseptal emphysema is easily detected by HRCT.[7] Subpleural bullae are usually considered to be a manifestation of paraseptal emphysema although they may be seen in all types of emphysema or as an isolated phenomenon. Bullae are generally defined as being larger than 1 cm .[8]

"Bullous emphysema" does not represent a specific pathologic entity, but is generally seen in association with centrilobular emphysema and/or paraseptal emphysema. However, a syndrome of bullous emphysema, or "giant bullous emphysema", has been described on the basis of clinical and radiologic features, and is also known as "vanishing lung syndrome", "type 1 bullous disease", or "primary bullous disease of the lung".[9] Giant bullous emphysema is often seen in young men, and is characterized by the presence of large, progressive, upper lobe bullae, which occupy a significant volume of a hemithorac. Most patients with giant bullous emphysema are cigarette smokers, but this entity may also occur in non-smokers. In patients with bullous

emphysema, HRCT better depicts the presence of associated paraseptal and centrilobular emphysema than do chest radiographs.

Utility of HRCT in Diagnosing Emphysema

HRCT is undoubtedly more sensitive than chest radiographs in diagnosing emphysema and in determining its type and extent.[4-7] Furthermore, HRCT has a high specificity for diagnosing emphysema; emphysema is rarely overcalled in normal individuals or in patients with severe hyperinflation due to other causes.[10]

However, in clinical practice HRCT is rarely used in an attempt to diagnose emphysema. Usually, the combination of 1) a smoking history, 2) a low diffusing capacity, 3) airways obstruction on pulmonary function tests, and 4) an abnormal chest radiograph showing large lung volumes is sufficient to make the diagnosis. However, some patients with early emphysema can present with clinical findings more typical of interstitial lung disease or pulmonary vascular disease, namely shortness of breath and low diffusing capacity, without evidence of airways obstruction on pulmonary function tests.[11] In such patients, HRCT can be valuable in detecting the presence of emphysema and exclu~ding an interstitial abnormality. If significant emphysema is found on HRCT, no further workup is necessary; specifically lung biopsy is not needed. In one study of 470 HRCT examinations,[12] there were 47 cases in which emphysema was the dominant or sole parenchymal abnormality. Of these 47, 16 lacked chest radiographic findings of emphysema, and 10 of these 16 had decreased single breath diffusing capacity (DLCoSB < 80% predicted) without evidence of airways obstruction (FEV1/FVC and FEV1 > 80 % predicted). In these patients the severity of emphysema scored on the HRCT correlated closely k = 0.8) with decreasing DLCoSB.

CT is also of value in the preoperative assessment of patients with bullous emphysema. In one study,[13] CT showed well defined bullae which were potentially resectable in 23 of 43 patients; 20 patients had bullae in association with generalized emphysema which were not amenable to surgical excision.

Large airway abnormalities – Bronchiectasis

Bronchiectasis is generally defined as localized, irreversible bronchial dilatation.[14] While bronchiectasis usually results from chronic infection, airway obstruction by tumor, stricture, impacted material, or inherited abnormalities also can play a significant role.[15]

Bronchiectasis results in characteristic abnormalities identifiable on HRCT in many patients.[16] These include bronchial dilatation, bronchial wall thickening, lack of normal bronchial tapering with visibility of airways in the peripheral lung, gross irregularities in airway contour, and mucus or fluid retention in the bronchial lumen. A diagnosis of bronchiectasis is usually based on a combination of these findings.

Since bronchiectasis is defined by the presence of bronchial dilatation, recognition of increased bronchial diameter is key to the CT diagnosis of this abnormality. Unfortunately, to date, no absolute CT criteria of normal bronchial diameter have been determined, and this diagnosis remains somewhat subjective. However, relating the size of bronchi to the size of adjacent pulmonary artery branches has proven helpful in the diagnosis of bronchiectasis; generally, bronchiectasis is considered to be present when the internal diameter of a bronchus is greater than that of the adjacent pulmonary artery branch [16]. The accuracy of this finding has been validated in a number of studies comparing CT to bronchography in patients with bronchiectasis.[14,17] In patients with bronchiectasis, the bronchial diameter is often much larger that the pulmonary artery diameter, a finding which not only reflects the presence of bronchial dilatation, but also some reduction in pulmonary artery size; the abnormal ventilation of lung parenchyma in regions of bronchiectasis results in decreased lung perfusion and a corresponding decrease in size of pulmonary arteries. The association of a dilated bronchus, with a much smaller contiguous pulmonary artery branch, has been termed the "signet-ring sign". This sign is quite valuable in recognizing bronchiectasis, and distinguishing it from other cystic lung lesions.

A simple comparison of bronchial and pulmonary artery sizes, however, may lead to the overdiagnosis of bronchiectasis. For example, Lynch et al[18] compared the internal diameters of lobar segmental, subsegmental, and smaller bronchi to those of adjacent pulmonary artery branches in 27 normal subjects. Fifty-nine percent of the normal subjects showed at least one bronchus with an internal diameter exceeding that of the adjacent pulmonary artery branch and 37 (26%) of 142 bronchi assessed in this group showed this finding.[18] Bronchiectasis should not be

diagnosed on the basis of increased bronchial diameter alone; bronchial wall thickening is almost always seen in associaiton with bronchiectasis, as are irregularities in bronchial diameter or lack of bronchial tapering. In the normal subjects studied by Lynch et al,[18] bronchial wall thickening was relatively uncommon, and it is unlikely that any of these patients would have been diagnosed on clinical HRCT studies as having true bronchiectasis.

Bronchiectasis has been classified into 3 types, depending on the morphology of the abnormal bronchi.[15,16] Each type of bronchiectasis has a characteristic appearance on HRCT, but their differentiation is not often of clinical significance. **Cylindrical bronchiectasis**, the mildest form of the disease, is characterized on HRCT by the presence of thick walled bronchi, which extending into the lung periphery and fail to show normal tapering. On HRCT, bronchi are not normally visible in the peripheral 3 cm of lung, but in patients with bronchiectasis, bronchial wall thickening, peribronchial fibrosis, and dilatation of the bronchi, allow them to be seen in this region. Depending on their orientation relative to the scan plane they can simulate "tram tracks" or can show the "signet-ring sign" .[15,16] Dilated bronchi can be filled with fluid, mucus, or pus. **Varicose bronchiectasis** is similar in appearance to cylindrical bronchiectasis; however, with varicose bronchiectasis the bronchi walls are more irregular, and can assume a beaded appearance. Varicose bronchiectasis is easiest to identify when the involved bronchi course horizontally in the plane of scan. Traction bronchiectasis is commonly varicose in appearance. The term "string of pearls" has been used to describe varicose bronchiectasis.[15,16] **Cystic bronchiectasis** can show several CT findings. The presence of a group or cluster of multiple air-filled cysts is most common; cysts can also be fluid filled, giving the appearance of a "cluster of grapes". Air-fluid levels in the dependent portions of the dilated bronchi are a very specific sign of cystic bronchiectasis. Combinations of these findings are common.

Utility of HRCT in Diagnosing Bronchiectasis

Using HRCT Grenier et ai [19,20], found a sensitivity of 96%, and a specificity of 93%, as compared with bronchography for diagnosing bronchiectasis.[14] Young et al[17] also assessed the reliability of HRCI in the assessment of bronchiectasis, as compared to bronchography. HRCT was positive in 87 of 89 segmental bronchi shown to have bronchiectasis (sensitivity 98%). HRCT was negative in 169 of 170 segmental bronchi without bronchiectasis at bronchography (specificity 99%).

SMALL AIRWAYS ABNORMALITIES

Centrilobular Opacities

Small airways abnormalities are common in patients with airways diseases, and are often the major site of airway obstruction. Morphologic abnormalities of the small airways in patients with airways disease include 1) wall thickening due to increased muscle thickness, inflammation, and fibrosis, 2) narrowing or obliteration of the bronchiolar lumen, 3) bronchiolar dilatation, and 4) mucus plugging or bronchiolar impaction with infected material.[2]

On HRCl, abnormal bronchioles filled with fluid, mucus, or pus can appear as centrilobular tubular, branching, or nodular structures.[21] The combination of fluid or pus filled bronchioles associated with some surrounding inflammation has been described using the term "tree-in-bud" ;[22] this appearance is usuallyj the result of diseases associated with mucus stasis or infection, such as panbronchiolitis, cystic fibrosis, diseases associated with chronic bronchial sepsis (e.g. ciliary dysmotility syndromes), and bronchopneumonia (caused by bacterial organisms or mycobacteria). For example, in its early stages, cystic fibrosis is commonly associated with centrilobular opacities representing mucus or pus-filled bronchioles[21] bronchiectasis is visible.[23,24]

Small airways diseases can also be associated with peribronchiolar, centrilobular opacities in the absence of "tree-in-bud"; such diseases are usually unassociated with infection or mucus stasis and examples include bronchiolitis obliterans and BOOP.[21]

HRCT findings of "tree-in-bud" or centrilobular nodules are often patchy in distribution. In many patients with small airways abnormalities visible on HRCT, large airways abnormalities such as bronchiectasis or bronchial wall thickening are also visible.

Mosaic Perfusion

Patchy areas of inhomogeneous lung attenuation are often visible on HRCT in patients with small airways abnormalities. These indicate the presence of perfusion abnormalities occurring as a result of abnormal

regional lung ventilation; this is termed "mosaic perfusion". In some patients, mosaic perfusion may be the only sign of an abnormality.[25] However, abnormal airways are often visible in the areas of decreased attenuation, and pulmonary arteries may appear smaller in these regions than in adjacent denser lung regions.

For example, bronchiolitis obliterans (constrictive bronchiolitis) is characterized by the presence of granulation tissue polyps within the lumina of bronchioles and alveolar ducts; narrowing of airways by scarring is associated with significant obstruction to airflow. Bronchiolitis obliterans is a nonspecific reaction which may be caused by a variety of insults, including toxic-fumes, infection, connective tissue diseases, particularly rheumatoid arthritis, and as a complication of bone-marrow and heart-lung transplantation. Patients with bronchiolitis obliterans typically present with symptoms and signs of airway obstruction.

The HRCT appearance of ibronchiolitis obliterans has been described in several studies.[3,23,26-29] Reported HRCT findings have been quite similar regardless of the cause of the abnormality. In addition to bronchiectasis, typical HRCT findings of bronchiolitis obliterans reflect the patchy ventilation and perfusion of lung which results from bronchial obstruction and air trapping. HRCT shows patchy or geographic areas of increased and decreased lung attenuation -"mosaic perfusion". Areas of lucency typically contain abnormal bronchi, and small or invisible pulmonary arteries.

Bronchiolitis obliterans is a major component of the Swyer-James or MacLeod syndrome. The bronchiolitis obliterans in patients with this syndrome is the result of lower respiratory tract infection, usually viral, occurring in infancy or early childhood. Damage to the terminal and respiratory bronchioles leads to incomplete development of associated alveoli. The radiographic hallmark of this syndrome is unilateral hyperlucent lung with reduced lung volume on inspiration and air trapping on expiration. Marti-Bonmati et al[28] described the CT findings in 9 patients with Swyer-James syndrome. On CT, in 8 patients, the affected lung showed decreased opacity; lung volume on the affected site was reduced in 6 patients and normal in three. In all patients, the size of the affected lung did not change on CT scans obtained during inspiration and expiration, reflecting the presence of air trapping. All 9 patients had CT findings of bronchiectasis.[28] In a recent study of 8 patients with Swyer-James syndrome, patchy areas of hyperlucency were visible on CT, even in lung regions which appeared normal on radiographs; bronchiectasis was present in only 3.[30]

CT/HRCT DEMONSTRATION OF AIR TRAPPING

A technique termed dynamic ultrafast high-resolution CT (DUHRCT) has recently been shown to be valuable in the diagnosis of air-trapping.[31,32] With DUHRCT, a series of ultrafast HRCT scans are rapidly obtained as the patient forcefully exhales, in order to demonstrate dynamic abnormalities of lung attenuation and morphology which result from air trapping. Post-expiratory HRCT scans obtained at selected levels can also be used to show air trapping.

On DUHRCT or post-expiratory HRCT scans, air trapping is considered to be present when the lung fails to increase normally in attenuation during exhalation. It has been shown in a number of studies that lung attenuation normally increases as lung volume decreases.[33] In the majority of normal subjects, lung attenuation increases in a homogeneous fashion during exhalation, with the average increase being 200HU. Areas of air-trapping can be recognized on expiratory HRCT as areas of abnormal lucency.[31,32] These findings can be seen in lung regions which appear morphologically normal on inspiratory HRCT, or show only a subtle inhomogeneity in lung opacity. In patients with findings of mosaic perfusion resulting from airways obstruction, lung inhomogeneities are accentuated on expiration.

In patients with airways obstruction and air-trapping of various causes, areas of lung which appear relatively lucent on exhalation show an increase in attenuation measuring less than 50 HU, or sometimes show a paradoxical decrease in attenuation of as much as -250 HU. Overall, the extent of air-trapping measured using DUHRCT.correlates closely with pulmonary function test measures of obstruction; correlation of FEV1, percent predicted, with the extent of air trapping measured using DUHRCT was highly significant.[32]

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