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Differentiation of causes of inhomogeneous lung density in high resolution computed tomography

HRCT is an imaging modality, which achieves optimum quality of anatomical lung structures, the modality of choice in assessment of lung parenchyma (1). It enables assessment of pathological changes at the level of lung lobule. The most important factors deciding of high resolution are thin collimation, 2–3 mm and image reconstruction with the sharp "bone" algorithm (1,4). HRCT enables imaging of subtle differences in lung density, invisible on plain radiograms and even in conventional computed tomography.

The aim of the study was the assessment of the diagnostic possibilities of HRCT in diagnosing and differentiating cases of inhomogeneous lung density.

MATERIAL AND METHOD

The material comprises a group of 48 patients, 33 men and 15 women, aged between 32 and 63 years. 17 patients had pneumoconiosis, 12 sarcoidosis, 8 patients were with parenchymal fibrosis, 7 with allergic alveolitis, and 4 patients had BOOP.

The HRCT examination was performed with the patients supine, on hold maximum inspiration. Additional expiratory sections were performed at the levels at which the pathology on inspiratory scans was found. The collimation was 2mm, with 10 mm scanning interval. The scanning was performed from apex to basis of the lung. In cases of posterior densities in dependent lung areas, additional prone scans were performed.

RESULTS

In 16 patients ground glass opacities were seen as a diffuse, patchy increase of the lung density, due to filling of alveoli and respiratory bronchioles with the inflammation exudation and tissue masses (Fig.1). The ground glass opacities in 6 patients reflected presence of allergic alveolitis. The patchy opacities of air-spaces formed area of ground glass opacities (Fig.2). In 2 cases ground glass opacities were unilateral, while the other lung showed emphysema (Fig. 3). In 12 cases opacities in posterior parts of the lung in patients in the supine positions reflected the presence of dependent opacities (Fig. 4). In 6 patients the parenchymal fibrosis coexisted with ground glass opacities (Fig. 5). The ground glass opacity coexisted 3-times with bullas and air-trappings (Fig. 6).

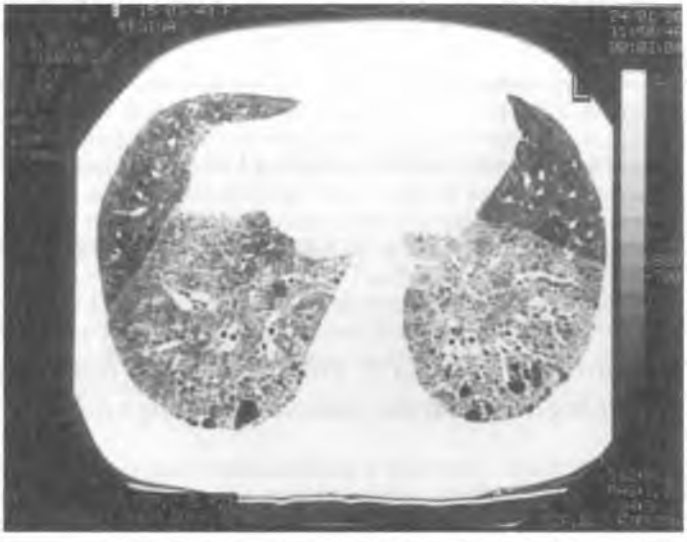

Fig. 1. The ground glass opacities in upper segments of lower lobes, more intense in posterior parts, due to patient's supine position

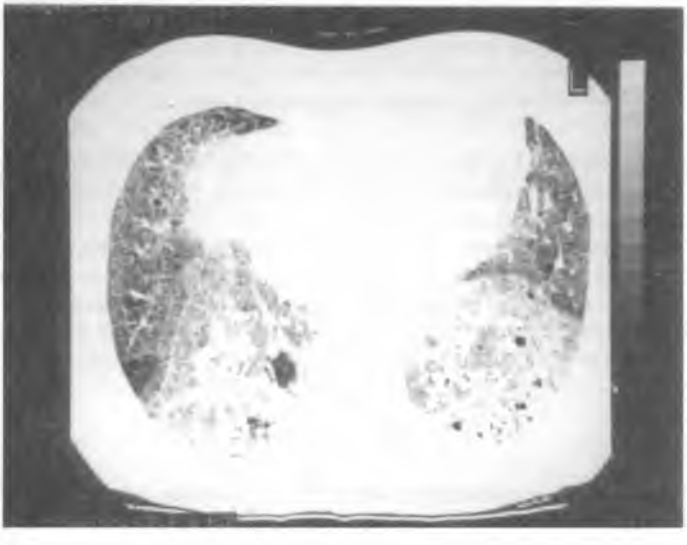

Fig.2. Patchy, shapeless ground glass opacities in allergic alveolitis

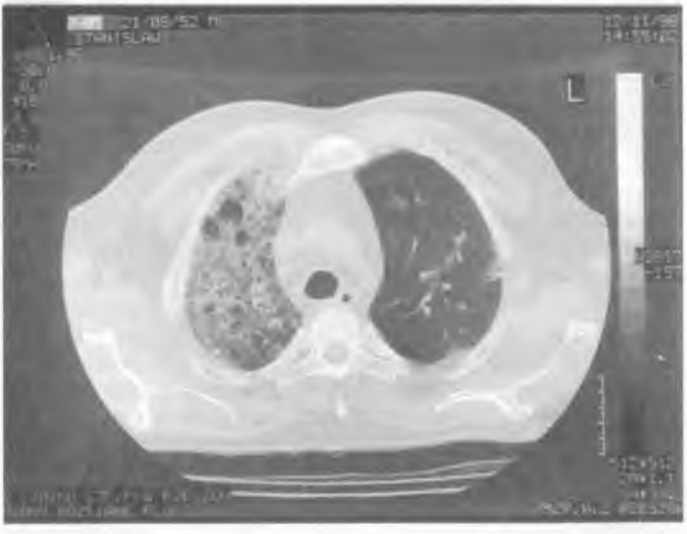

Fig.3. Right lung with fusing ground glass opacities, left lung emphysematous hyperlucent

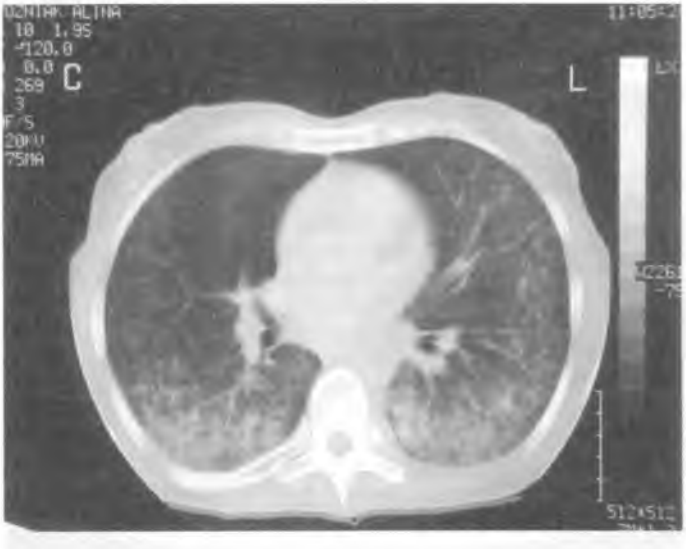

Fig.4. Patchy opacities in posterior parts of the lung in patients in supine position, reflecting the presence of dependent opacities

The prone patients positions in maximum expiration enabled imaging of air-trapping, caused by obstruction of small bronchi. The dynamic examination in various respiratory phases revealed areas of hyperlucency not showing normal expiratory increase in density. Comparative expiratory and inspiratory scans revealed and enabled evaluation of the extent of focal air-trapping areas. Physiological expiratory increase in density clearly contrasted with the multiple areas with retained air.

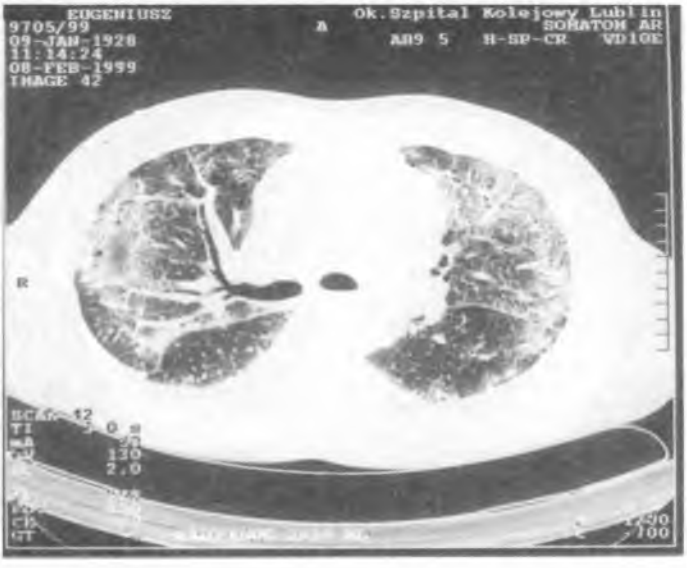

Fig. 5. Diffuse reticular fibrosis as irregular linear pattern with the presence of ground glass opacities in peripheral areas of both lungs, with the air bronchogram

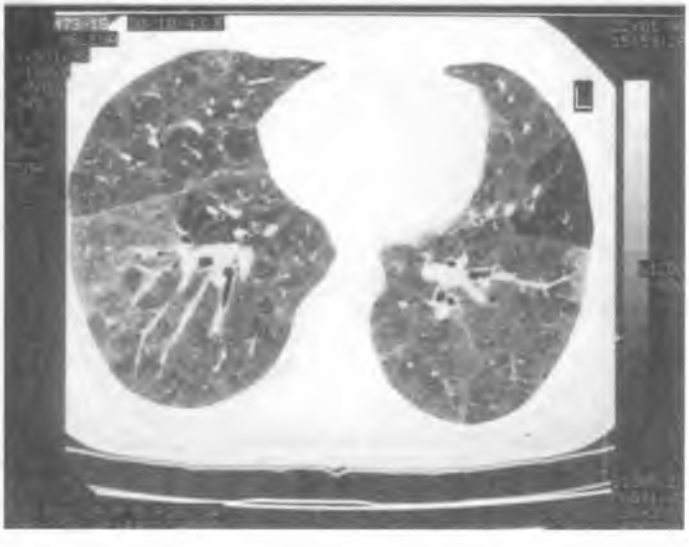

Fig. 6. Patchy ground glass opacities without obscuration of underlying lung arteries

DISCUSSION

The causes of inhomogeneous lung density in HRCT are changes contributing to increasing or decreasing of lung density, usually patchy distributed. They include ground glass opacities, air-trapping and mosaic perfusion, due to bronchiolar or vascular obstruction (22).

In ground glass opacities expiratory HRCT showed proportional increase of both areas of higher and lower densities. The same is true in the mosaic perfusion caused by the vascular pathologies.

The ground glass opacities is a term referring to the presence of hazy increase in lung opacity without obscuration of underlying vessels (3,19). If the vessels are obscured, the term consolidation is used (3). The ground glass opacities result from volume averaging of morphologic abnormalities below the resolution of HRCT. They can reflect the thickening of septal or alveolar parenchyma and alveolar walls, presence of inflammatory cells or fluid partially filling the alveolar spaces (6,18). Small amount of fluid within alveoli in early stages of an air-space filling disease, tends to layer against the alveolar walls, and is indistinguishable on HRCT from alveolar wall thickening, causing the ground glass opacities. The ground glass opacities are usually patchy distributed, affecting some lung regions, while others are spared (22). The presence of ground glass opacities is a highly significant finding, often indicating the presence of an ongoing, active and potentially treatable process (12,17,19,22).

Ill-separated subpleural opacities, are usually visible in posterior lung areas in the supine patients, in so called dependent areas (dependent opacities). They result from gravitational effect, which causes arising of opacities simulating pulmonary fibrosis. They disappear in the prone position of the patients. The prone position reveals early pathological changes in the posterior lung areas, when they remain visible. They are often seen in sarcoidosis (32–36%) and idiopathic pulmonary fibrosis (9–12%). Because ground glass opacities can reflect presence of both fibrosis and inflammation, the active, treatable process should be recognized only in cases without evident fibrosis on HRCT, or if they are dominant changes (19). HRCT enables differentiating active, potentially treatable alveolitis from irreversible fibrosis, without the need of lung biopsy (22). After treatment the improvement was seen in 80% of patients with ground glass opacities, in 20% of patients with mixed picture on HRCT and in 4% of patients with dominating reticular pattern (23).

Allergic alveolitis form bilateral, partially confluent ground glass opacities with the reduction of pulmonary markings. The ground glass opacity on HRCT requires differentiating first of all with areas of the mosaic perfusion and air-trapping (22). The diffuse, patchy or nodular opacities should be differentiated with the mosaic perfusion. 12% of them represent diseases of air spaces, 34% represent mixed interstitial and air spaces changes, 54% represent mainly interstitial pathology (22).

The ground glass opacities on HRCT performed on hold deep inspiration, with the wide window width (1500-2000 HU) may be shapeless, forming slight density increase, usually patchy hazing, not obscuring underlying vessels and bronchial walls (22). They can form the mosaic perfusion patterns in central portions of the lobules. They are the most frequent in the allergic alveolitis, where alveoli are filled with hyaline membranes creating areas of patchy density. Active alveolitis and slight fibrosis are potentially treatable and reversible (22).

In hypersensitivity pneumonia and bronchiolitis the patchy or nodular densities may be intralobular, and in parenchymal inflammations the walls of alveoli and septa are affected. In ground glass opacities early or active inflammatory changes affected alveolar areas and septa. In organizing pneumonia the combination of ground glass opacities and smooth interlobular septa thickening, called "crazy paving" form patchy distribution of changes. The ground glass opacities may reflect both the filling of alveoli and centrilobular interstitial changes, which may form picture from intralobular nodules to confluent areas, often sharply separated from the normal parenchyma. That suggests active, potentially reversible changes (22). The areas of ground glass opacities with traction bronchiectasis and bronchiolectasis are places of

irreversible fibrotic changes. Slight lesions of small airways reveal air-trapping and mosaic perfusion. The depended lung areas show higher expiratory increase in density than nondepended areas. The density increase was about 150–300 HU (21,22). The differences of density increase between posterior and anterior areas in supine patients positions are about 50–100 HU (247). In supine position mean density in posterior third part of the lungs is about – 766.2 HU and – 844.4 HU in the anterior one (15).

Changing the patient's position allows excluding hydrostatic densities and apparent changes, eliminating gravitational effect caused by reduction of the lung volume due to pressure. This enables differentiating potentially treatable changes from irreversible fibrosis, edematous changes of atelectasis from early fibrosis and assessing the degree of the diseases (21,22).

The influence of gravitation on the blood flow and its distribution is important in assessment of HRCT sections in different patient's positions. The dependent lung areas contain relative less air. Subpleural increase in density on inspiratory scans may be due to the increased amount of blood in the dependent lung areas, and decreased amount of air in posterior, subpleural parts of the lungs (9,10). The density increase may be caused by the changes in the air spaces or in the extra-vascular parenchyma, and because of increased amount of blood in the capillaries. The reduction in the amount of air in those lung areas, without destruction of the parenchyma causes increased lung density of ground glass character (21).

The density coefficient depends on the gravitation influence on blood supply. It is different in dependent and nondependent lung areas in standing, lying and lateral positions. The most often cases of ground glass opacities involve interstitial pneumonia, bronchiolitis obliterans, sarcoidosis and hypersensitivity pneumonia (11,16).

On HRCT, inhomogeneous lung opacity can result from regional differences in lung perfusion in patients with airways diseases or vascular diseases. Because this phenomenon is often patchy, or mosaic in distribution, with adjacent areas of relative increase or decrease lung density, it has been termed mosaic perfusion (3). Almost all cases of mosaic perfusion are accompanied by diseases causing regional decreases of lung perfusion. The differences in attenuation between normal and abnormal lung regions, visible on HRCT, are accentuated by compensatory increased perfusion of normal or relatively normal lung areas (22). Mosaic perfusion is the most frequent in the lung diseases, that result in focal air-trapping or poor ventilation of lung parenchyma. The areas of poorly ventilated lung are poorly perfused because of reflex vasoconstriction or because of permanent reduction of the capillary bed. The coincidence of mosaic perfusion and air-trapping is characteristic in lymphagitis carcinomatosa, cystic fibrosis and bronchiectasis (7,13).

In mosaic perfusion, lung vessel in the areas of decreased opacity often appear smaller than vessels in relative dense areas of lung. This difference reflects differences in regional blood flow, and they may be helpful in distinguishing mosaic perfusion from ground glass opacities, which may be of similar patchy distribution. In cases of ground glass opacity, vessels usually appear equal in size throughout the lung (22).

The air-trapping are regions of decreased lung density, remaining lucent on expiratory HRCT scans. Diagnosis of air-trapping is difficult in patients, that cannot hold breathing. In such cases the HRCT in lateral decubitus is suggested (5,8). The most common causes of air-trapping are bronchiolitis obliterans, bronchiectasis, mycobacterial pneumonia, cystic fibrosis, allergic alveolitis, sarcoidosis, histiocytosis X (3,25). The mosaic perfusion results from improper lung ventilation, creating differences in regional lung density (22).

Post expiratory HRCT can be helpful in differentiating mosaic perfusion resulting from airways obstruction from ground glass opacities, because the differences in density are accentuated in cases of mosaic perfusion, and in cases of ground glass opacities they are not. The areas of increased density measured about –727 HU and decreased density –868 HU.

Mosaic perfusion is frequent in bronchiolitis obliterans, diseases with air-trapping, poor lung ventilation, permanent reduction of vascular bed, small airways obstruction,

bronchiectasis, fibrosis (24). Inhomogeneous lung density on inspiratory HRCT section can be result of infiltration with ground glass opacity, air-trapping in airways diseases or vasoconstriction resulting in mosaic perfusion (22)

The contrast between areas of normal lung density and areas of ground glass opacities may form the mosaic pattern. The similar pattern can be result of differences between low density areas, with air-trapping on expiratory scans, and areas of increased lung density resulting from both ground glass opacity and corresponding to normal lung parenchyma (22).

In patients with asthma areas of mosaic perfusion are evident on inspiratory scans in 23% of patients. They can be explained by the regional hyperinflation of lung and hypoxic constriction of lung vessels (22). The areas of decreased lung density in expiratory air-trapping together with patchy differences in lung density on expiratory scans form mosaic perfusion pattern. Those were areas of increase and decrease lung density, patchy on deep inspiration. In ground glass opacities, the expiratory HRCT sections show proportional increase in density both in areas of increased and decreased density. In mosaic perfusion the differences of lung density are accentuated on expiration; the relative density areas increase in attenuation, while lower attenuation regions remain lucent (22).

Expiratory HRCT scans are also valuable in distinguishing inhomogeneous density resulting from presence of emphysema or air trapping. In airways obstruction and presence of air-trapping the lung remain lucent on expiratory and show little change in the area. The diagnosis of air-trapping on expiratory HRCT is easy, when the abnormality is patchy in distribution, and normal lung regions can be contrasted with abnormal, hyperlucent lung regions on expiratory scans (22).

In cases of inhomogeneous lung density resulting from presence of ground glass opacities in infiltrative diseases, increase in density is visible on expiratory scans in both areas of increased and decreased lung density (2,25). Although limited value of expiratory HRCT the presence of air-trapping indirectly indicated on pathology of small airways (14,20).

CONCLUSIONS

The presence of inhomogeneous lung density in HRCT examination can be a result of ground glass opacities, air-trapping, and mosaic perfusion. These signs are visible only on HRCT scans and are involved with gravitational effect and respiratory mechanism. The expiratory HRCT scans are very important in differentiating causes of inhomogeneous lung density.

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SUMMARY

HRCT is a method of imaging, which achieves optimum quality of anatomical lung structures, the modality of choice in assessment of lung parenchyma. It enables assessment of pathological changes at the level of lung lobule. The most important factors, deciding of high resolution are thin collimation, 2-3 mm and image reconstruction with the sharp "bone" algorithm.

HTCT enables imaging of subtle differences in lung density, invisible on plain radiograms and even in conventional computed tomography. The aim of the study was the assessment of the diagnostic possibilities of HRCT in diagnosing and differentiating cases of inhomogeneous lung density. The presence of inhomogeneous lung density in HRCT examination can be result of ground glass opacities, air-trapping, and mosaic perfusion. These signs are visible only on HRCT scans and are involved with gravitational effect and respiratory mechanism. The expiratory HRCT scans are very important in differentiating causes of inhomogeneous lung density.

Różnicowanie przyczyn niejednorodnej gęstości płuc w tomografii komputerowej wysokiej rozdzielczości

TKWR jest metodą obrazowania, która umożliwia uzyskanie optymalnej jakości obrazów struktur anatomicznych płuc i jest metoda diagnostyczną z wyboru w ocenie miąższu. Umożliwia ocenę zmian patologicznych na poziomie zrazika płucnego. Najważniejszymi czynnikami decydującymi o wysokiej rozdzielczości są cienka kolimacja i rekonstrukcja obrazu z wykorzystaniem ostrego, „kostnego" algorytmu. Badanie TKWR umożliwiło uwidocznienie subtelnych różnic gęstości tkanki płucnej, niewidocznych na radiogramach i klasycznej tomografii komputerowej. Celem pracy była ocena możliwości diagnostycznych TKWR w rozpoznawaniu i różnicowaniu przyczyn niejednorodnej gęstości płuc. Obecność niejednorodnej gęstości płuc w badaniu TKWR może być spowodowana różnymi przyczynami o charakterze zacienień szkła mlecznego, pułapek powietrznych, perfuzji mozaikowej. Objawy te występują prawie wyłącznie w technice TKWR i są związane z efektem grawitacyjnym i mechanizmem oddechowym. Wykonanie badania TKWR ma istotne znacznie w różnicowaniu niejednorodnej gęstości płuc.