Ⅲ．研究成果の刊行に関する一覧表

研究成果の刊行に関する一覧表

雑誌

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Hayashi H, Ashizawa K, Takahashi M, Kato K, Arakawa H, Kishimoto T, Otsuka Y, Noma S, Honda S	The diagnosis of early pneumoconiosis in dust-exposed workers：comparison of chest radiography and computed tomography	Acta Radiol	Advance online publication		2021
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Original Article

The diagnosis of early pneumoconiosis in dust-exposed workers: comparison of chest radiography and computed tomography

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Hideyuki Hayashi[1], Kazuto Ashizawa[2], Masashi Takahashi[3], Katsuya Kato[4], Hiroaki Arakawa[5], Takumi Kishimoto[6], Yoshinori Otsuka[7], Satoshi Noma[8] and Sumihisa Honda[9]

Abstract

Background: Chest radiography (CR) is employed as the evaluation of pneumoconiosis; however, we sometimes encounter cases in which computed tomography (CT) is more effective in detecting subtle pathological changes or cases in which CR yields false-positive results.

Purpose: To compare CR to CT in the diagnosis of early-stage pneumoconiosis.

Material and Methods: CR and CT were performed for 132 workers with an occupational history of mining. We excluded 23 cases of arc-welder's lung. Five readers who were experienced chest radiologists or pulmonologists independently graded the pulmonary small opacities on CR of the remaining 109 cases. We then excluded 37 cases in which the CT data were not sufficient for grading. CT images of the remaining 72 cases were graded by the five readers. We also assessed the degree of pulmonary emphysema in those cases.

Results: The grade of profusion on CR (CR score) of all five readers was identical in only 5 of 109 cases (4.6%). The CR score coincided with that on CT in 40 of 72 cases (56%). The CT score was higher than that on CR in 13 cases (18%). On the other hand, the CT score was lower than that on CR in 19 cases (26%). The incidence of pulmonary emphysema was significantly higher in patients whose CR score was higher than their CT score.

Conclusion: CT is more sensitive than CR in the evaluation of early-stage pneumoconiosis. In cases with emphysema, the CR score tends to be higher in comparison to that on CT.

Keywords
Pneumoconiosis, chest radiography, computed tomography, chest, pulmonary emphysema

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Introduction

Pneumoconiosis, an occupational lung disease caused by the inhalation of silica, coal particles, or asbestos, still has a serious effect on occupational health worldwide (1). Silicosis, a pneumoconiosis, is an incurable lung disease caused by the inhalation of dust containing free crystalline silica. Early recognition is important

[1]Department of Radiology, Isahaya General Hospital, Nagasaki, Japan
[2]Department of Clinical Oncology, Nagasaki University Graduate School of Biomedical Sciences, Nagasaki, Japan
[3]Department of Radiology, Yujin-Yamazaki Hospital, Shiga, Japan
[4]Department of Radiology, Kawasaki Medical School Hospital, Okayama, Japan
[5]Department of Radiology, Dokkyo Medical University, Tochigi, Japan
[6]Asbestos Research Center, Okayama Rosai Hospital, Okayama, Japan
[7]Department of Internal Medicine, Hokkaido Chuo Rosai Hospital, Hokkaido, Japan
[8]Department of Radiology, Tenri Hospital, Tenri, Japan
[9]Department of Public Health & Nursing, Nagasaki University Graduate School of Biomedical Sciences, Nagasaki, Japan

Corresponding author:
Kazuto Ashizawa, Department of Clinical Oncology, Unit of Translational Medicine, Nagasaki University Graduate School of Biomedical Sciences, 1-7-1 Sakamoto, Nagasaki 852-8501, Japan.
Email: ashi@nagasaki.u.ac.jp

in the management of this disease. Early-stage pneumoconiosis is defined as profusion 0/1 to 1/1 cases on chest radiography (CR) based on the international classification of radiographs of pneumoconiosis published by International Labour Office (ILO) (2,3). Because they do not have pulmonary dysfunction, a radiological examination is essential for the diagnosis of pneumoconiosis for both clinical and epidemiological purposes (1). Although workers with possible exposure to occupational dust are screened using CR, there are some limitations in the assessment of pneumoconiosis on CR.

Computed tomography (CT) is more sensitive than CR in detecting lung parenchymal abnormalities. CR as well as CT findings in patients with silicosis have been documented, and it has been reported that discordance between the two was high, especially for CR-negative and early-stage pneumoconiosis cases (2). In addition, we sometimes encounter cases in which nodules, which are suspected on CR, are not evident on CT, especially in patients with pulmonary emphysema. The aim of the present study was to compare the CR and CT findings in the diagnosis of early-stage pneumoconiosis. Moreover, we also would like to evaluate whether the presence or degree of pulmonary emphysema is associated with the CR and CT scores.

Material and Methods

The present retrospective study was approved by the institutional review board of our hospitals, and the requirement for informed written consent was waived from all participants.

Patients

CR and CT examinations were performed for 132 workers with an occupational history of mining, who were recruited from two laborers' hospitals. Because the imaging findings of arc-welder's pneumoconiosis are different from those of silicosis (4), we excluded 23 cases of arc-welder's lung (Fig. 1). Thus, 109 individuals (109 men; age range = 48–89 years; mean age = 74.8 years) with silicosis or coal workers' pneumoconiosis were included. They included 25 smokers, 72 ex-smokers, and 12 never-smokers. None of the workers in the study had a history of pulmonary disease, such as tuberculosis, pneumonia, or lung cancer.

Interpretation of chest radiography

Posteroanterior CR was taken at full inspiration. CR images were displayed in 3-megapixel LCD medical-grade gray-scale monitor (Radiforce GS 320; Eizo, Ishikawa, Japan). Five readers, who were experienced chest radiologists (MT, KK, and SN, with 21–35 years of experience) or pulmonologists (TK and YO, with 27 and 15 years of experience, respectively) independently graded the profusion of lung abnormalities on CR of 109 cases in comparison to a set of standard radiographs provided by Ministry of Health, Labour and Welfare Labour Standards Bureau. In this set, CR findings are classified into one of seven PR (profusion) categories (PR 0, 1, 2, 3, 4A, 4B, and 4C). No radiographic signs of pneumoconiosis are graded as PR0 and those with pneumoconiotic small opacities as PR1–PR3, depending on increasing number

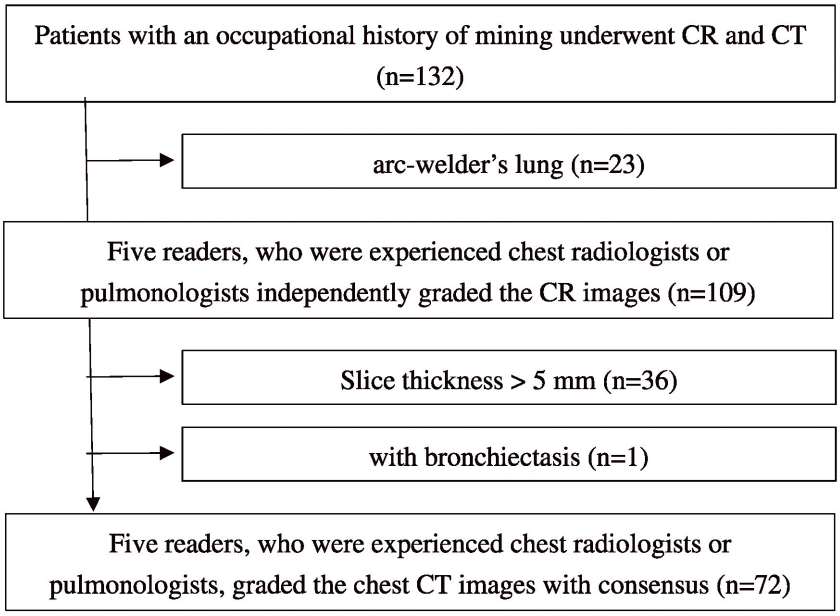

Fig. 1. Study selection process.

Table 1. Observer performance of the experienced chest radiologists or pulmonologists in the interpretation of CR images (n = 109).

CR score	5/5 agreement	4/5 agreement	3/5 agreement
0/1	4	14	11
1/0	1	7	28
1/1	0	3	14
>1/1	0	2	4
Total	5 (4.6%)	26 (24%)	57 (52%)

CR, chest radiography.

(profusion), and large opacities as PR4. Small opacities profusion is recorded on a 12-point scale from 0/– to 3/+, in which 0/– indicates no abnormality and 3/+ signifies the highest concentration of small opacities. We analyzed the observer performance of the five readers in the interpretation of CR. After the analysis of their scores (Table 1), the images from cases for which there was disagreement among the reviewers were reviewed to reach a consensus.

Interpretation of CT

All individuals were scanned in two CT scanners (TSX-302A/1A Aquilion PRIME (Toshiba Medical Systems, Tochigi, Japan) and Light Speed VCT (GE Healthcare, Chicago, IL, USA). Because of the retrospective design of this study, various CT scan protocols were used, and CT images were obtained with slice thicknesses in the range of 3–8 mm and slice intervals in the range of 5–8 mm at full inspiration. We excluded 36 cases with a slice thickness of >5 mm, and one case with marked bronchiectasis in the interpretation of CT images (Fig. 1). CT images were also displayed in 3-megapixel LCD medical-grade gray-scale monitor (Radiforce GS 320; Eizo, Ishikawa, Japan). All CT images were viewed on lung window setting (level = –700 HU; width = 1500 HU). Five readers also graded the profusion of lung abnormalities on CT images of 72 cases with consensus.

We compared the scores in both the CR and CT images. Two other experienced chest radiologists (HH and KA, with 22 and 30 years of experience, respectively) evaluated each CT image and classified the degree of emphysema into three levels: none; mild; and severe. These three levels correspond to the classification in the Fleischner Society guidelines as follows: none = none or trace; mild = mild or moderate; and severe = confluent or advanced destructive (5). The relationship between the degree of emphysema and the CR/CT scores was examined.

Table 2. Comparison of both CR and CT scores (n = 72).

	CT score			
CR score	0/1	1/0	1/1	1/<1
0/1 (n = 27)	21	5	0	1
1/0 (n = 27)	13	9	4	1
1/1 (n = 15)	3	2	8	2
1/<1 (n = 3)	0	1	0	2

CR, chest radiography; CT, computed tomography.

Table 3. Correlation between the degree of pulmonary emphysema and CR/CT scores (n = 72).

Pulmonary emphysema	CR > CT	CR = CT	CR < CT
None (n = 43)	5	26	12
Mild (n = 21)	7	13	1
Severe (n = 8)	7	1	0

CR, chest radiography; CT, computed tomography.

Data analysis

The weighted value of kappa was calculated for the comparison of CR and CT scores (Table 2). Spearman's rank correlation coefficient was calculated to assess the correlation between the degree of pulmonary emphysema and the CR/CT scores (Table 3).

Results

The observer performance in the interpretation of CR images is shown in Table 1. The scores of all five observers were identical in only 5 of 109 cases (4.6%). There were 26 cases (24%) in which the scores of four of the five observers matched. There were 57 cases (52%) in which the scores of three of the five observers matched.

A comparison of CR and chest CT according to the categories is shown in Table 2. The weighted value of the kappa coefficient between the CR and CT scores was 0.456 ($P < 0.01$). 21 out of 27 cases with a CR score of 0/1 matched the score of the CT images. Six cases with a CR score of 0/1 were scored as 1/0 (n = 5) or 1/<1 (n = 1) on CT images. Five cases with a CR score of 1/0 were scored as 1/1 (n = 4) or 1/<1 (n = 1) on CT images. Two cases with a CR score of 1/1 were scored as 1/<1 (n = 2) on CT images. Therefore, there were 13 cases in which the CT score was higher than the CR score (Fig. 2). On the other hand, there were 19 cases in which CR score was higher than the CT score (Fig. 3).

The correlation between the degree of pulmonary emphysema and the CR/CT scores is shown in Table 3. The incidence of pulmonary emphysema was significantly higher (r = 0.503; $P < 0.001$) in cases in which the CR score was higher than the CT score.

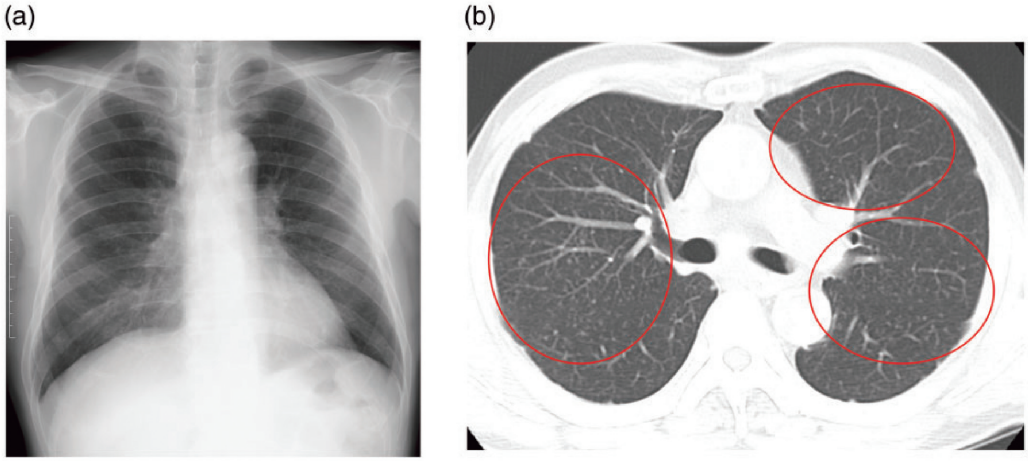

Fig. 2. (a) A 72-year-old man with an exposure duration of 30 years. Chest radiography was judged as profusion 0/1. (b) Computed tomography images revealed many small opacities in the lung parenchyma (circles).

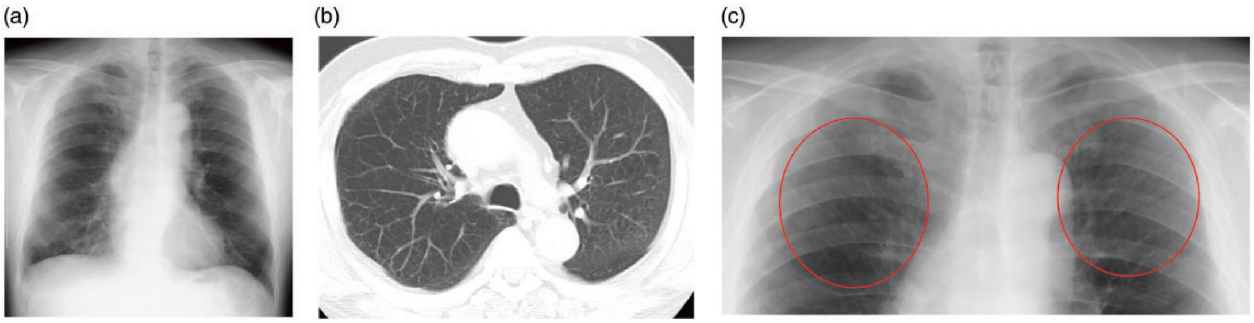

Fig. 3. (a) An 81-year-old man with an exposure duration of 34 years. CR was judged as profusion 1/1. (b) Computed tomography images revealed pulmonary emphysema with a few small opacities in the lung parenchyma. (c) Magnified image of the upper lung fields of CR (a). There appear to be small nodules in the upper lung fields (circles). CR, chest radiography.

Discussion

In the present study, CT is more sensitive than CR in the evaluation of pneumoconiosis. Pneumoconiosis is usually diagnosed based on CR. Currently the diagnosis is based on the international classification of radiographs of pneumoconiosis, published by the ILO in 1980 (3); however, CR is of limited value in cases of low-grade diffuse infiltrative lung disease (6,7). In this study, 18% (13/72) of cases had small nodular lesions that could only be detected on CT, or in which more nodules could be detected by CT. There are some cases in which tiny nodules can only be depicted on CT. Suganuma et al. (8) reported that the CR categorical classification was similar to high-resolution CT (HRCT), with the exception of category 0, in which HRCT was more sensitive.

In patients with pulmonary emphysema, the CR score tended to be higher than the CT score. Although Savranlar et al. (2) also reported that the CR categorical score was higher than the CT score in 15 of 67 patients, the reason was not shown. Patients with silicosis often have pulmonary emphysema. Bergin et al. (9) reported that pulmonary emphysema associated with silicosis was easily detected on CT. To the best of our knowledge, there are no reports on the overestimation of silicotic nodules by correlated with pulmonary emphysema.

It is difficult to diagnose pulmonary emphysema based on CR alone. Thurlbeck and Simon (10) described two different roentgenologic patterns of altered pulmonary vascularity in patients with pulmonary emphysema, namely, "arterial deficiency" and "increased marking". "Increased marking" refer to prominent vascular markings which tend to be irregular in contour. This pattern is thought to occur in patients with mild or moderate emphysema due to redistribution of blood flow, pulmonary arterial hypertension and lung overinflation. We hypothesize that the presence of "increased marking" is one of the factors associated with overestimation of tiny nodules on CR.

Although image interpretation was performed by experienced radiologists or pulmonologists in this study, there were only 5 cases (4.6%) in which all five scores of pneumoconiosis on CR matched. The diagnosis is based on the international classification of radiographs; however, the criterion is ambiguous due to the number of nodules. Since this ambiguity cannot be completely eliminated, even by CT, we are of the opinion that objective evaluation by a system such as computer-assisted diagnosis will be necessary in the future.

The present study has some limitations. First, this was a retrospective study. Second, the study population was relatively small. Third, the slice thickness of CT was relatively thick, not thin-section CT, because CT scans with thick slice thickness have been performed in the past for screening purposes at many institutions, and they are performed in some institutions in our country, even at the present time. Therefore, this limitation might influence the CT profusion score.

In conclusion, CT is more useful than CR in the evaluation of pneumoconiosis. In addition to depicting tiny nodules, we could reduce overestimation, especially in cases with pulmonary emphysema. We suggest using CT as a standard screening method to distinguish between normal and early-stage pneumoconiosis.

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Declaration of conflicting interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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ORCID iD

Kazuto Ashizawa https://orcid.org/0000-0001-6726-1297

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一般社団法人　電子情報通信学会
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信学技報
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3 次元 CT 画像による じん肺重症度の肺葉別粒状影解析

橋本 悠雅† 松廣 幹雄‡ 鈴木 秀宣‡ 河田 佳樹‡
大塚 義紀†‡ 岸本 卓巳‡‡ 芦澤 和人†‡‡ 仁木 登‡‡‡
†徳島大学大学院 創成科学研究科〒770-8502 徳島県徳島市南常三島町 2-1
‡徳島大学大学院 社会産業理工学研究部 †‡北海道中央労災病院
‡‡岡山ろうさい病院 †‡‡長崎大学
‡‡‡株式会社医用科学研究所

E-mail: †c612136006@tokushima-u.ac.jp

あらまし じん肺は，粉じんを肺に吸入することによって生じる職業性呼吸器疾患である．我国において毎年 24 万人前後の粉じん労働者がじん肺健康診断を受診している．じん肺の診断では単純 X 線写真を用いているが，近年では単純 X 線写真に比べて正確に病変を評価することができる 3 次元 CT 画像を用いた高精度な診断が期待されている．本研究では，3 次元 CT 画像を用いてじん肺の診断支援システムの開発を目指している．このために，3 次元 CT 画像を用いて粒状影を抽出し，粒状影数，発生位置を比較することで重症度を評価する．

キーワード CT，CAD，医用画像処理，じん肺

1. 背景・目的

じん肺は，粉じんを肺に吸入することによって生じる職業性呼吸器疾患である．日本の粉じん作業従事労働者数は昭和 60 年をピークに減少し，平成 12 年で 35 万人であったが，近年は約 50 万人前後で推移しており増加傾向となっている．じん肺が進行すると肺結核・続発性気胸・肺がんなどの合併症に罹患しやすくなるため，健康診断で適切な診断・治療が必要である．

また，じん肺健康診断として胸部単純 X 線撮影や肺機能検査が実施されている．胸部単純 X 線写真によって病型が第 0 型，第 1 型，第 2 型，第 3 型，第 4 型に分類され，さらに各型で 3 つに分類される．第 1 型 1/0 以上の患者は労災認定となるが第 0 型 0/1 の患者は労災認定の対象とならないため正確に診断しなければならない．近年では単純 X 線写真に比べて正確に病変を評価することができる 3 次元 CT 画像を用いた高精度な診断が期待されている．そこで本研究では，3 次元 CT 画像を用いてじん肺の診断支援システムの開発を目指している．このために，CT 画像を用いてじん肺の粒状影を葉別に抽出し，粒状影の個数と分布の割合を重症度別に比較することで定量的に重症度を評価した．

2. 撮影条件と手法

岡山ろうさい病院と北海道中央労災病院で撮影され，CT を用いて診断された炭坑夫肺 15 症例(CT0/1 - 6 例，CT1/0 - 6 例，CT1/1 - 3 例)とけい肺 11 症例(CT0/1 - 6 例，CT1/0 - 5 例，CT1/1 2 例)を用いた．症例別の病型区分と症例数を表 1 に示し，撮影条件を表 2 に示す．これらの CT 画像から(1)じん肺 CT 画像データベースの作成，(2) 肺葉分割ラベルの作成，その結果を用いて(3) じん肺の肺葉別粒状影の評価をし，第 0 型 0/1 と第 1 型 1/0，1/1 の比較評価を行った．

表 1　病型区分と症例数

けい肺		炭坑夫肺	
病型区分	症例数	病型区分	症例数
CT　0/1	6症例	CT　0/1	6症例
CT　1/0	5症例	CT　1/0	6症例
CT　1/1	2症例	CT　1/1	3症例
合計	13症例	合計	15症例

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表 2　撮影条件

撮影施設	岡山ろうさい	北海道中央労災
装置	Aquilion PRIME	LightSpeed VCT
管電圧[kV]	120	120
管電流[mA]	240	167~698
スライス厚[mm]	1.0	1.25
画素間隔[mm]	0.625 , 0.781	0.527~0.742
再構成間隔[mm]	1.0	1.25
再構成関数	FC-13H , FC52	STANDARD LUNG

(1) じん肺 CT 画像データベースの作成

じん肺の粒状影をマニュアル処理で抽出する．肺野条件(WW:1500,WL:-500)で右肺尖部から肺底部，左肺尖部から肺底部の順に粒状影をマニュアルで抽出する．初めに，粒状影を 3 次元 CT 画像からマニュアルで抽出した．読影者は 1 名または 2 名で行い，1 人で抽出した場合，期間を空け，2 度読影をした．2 人で抽出した場合は，1 人ずつ 1 度読影をし，合議によって最終抽出結果を作成した．

(2) 肺葉分割ラベルの作成

肺の分割は 3D U-Net を使用し，右肺を上葉，中葉，下葉に左肺を上葉，下葉の 5 分割にした．学習データは 300 症例用いた．

(3) じん肺の肺葉別粒状影の評価

じん肺の粒状影の位置を重心点と定義して，肺葉分割ラベルから肺葉別に粒状影を分類する．肺葉別粒状影について，重症度ごとの肺葉別粒状影数と分布の割合によって評価する．ボンフェローニ補正 t 検定を用いて，粒状影数，分布の割合に有意差があるか調べ，重症度と肺葉別粒状影数や割合に関係性があるか確認した．

3. 結果

(1) じん肺 CT 画像データベースの作成

図 1 に炭坑夫肺の粒状影の大きさ別 3 次元表示を示す．上から第 0 型 0/1，下左が第 1 型 1/0，右が第 1 型 1/1 となっている．重症度が上がるにつれ，粒状影数が多く，直径も大きくなっていることが分かる．

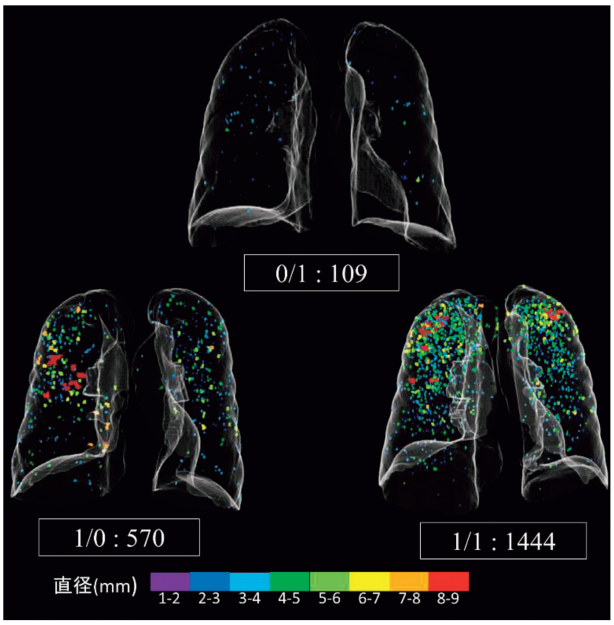

図 1　粒状影の抽出結果

(2)肺葉分割ラベルの作成

図 2 に炭坑夫肺 0/1 と 1/0 の症例を葉別に 5 分割した 3 次元表示を示す．赤が右上葉，黄緑が右中葉，青が右下葉，紫が左上葉，黄色が左下葉となっている．1/1 以降の症例は肺気腫が多い症例や，中葉が変形している症例，分葉不全の症例があり，正確に分割できていない部分はマニュアルで補正をした．

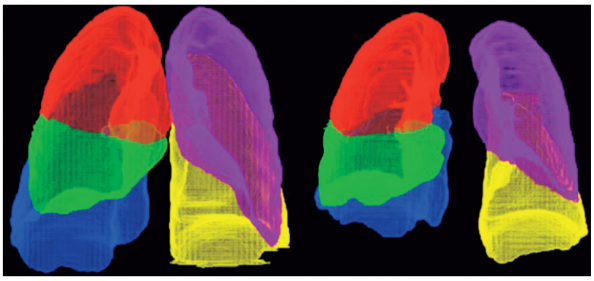

図 2　肺葉分割

(3)じん肺の肺葉別粒状影の評価

図 3 に重症度ごとの肺葉別平均粒状影数を示す．じん肺の粒状影は右上葉に多く存在し，右中葉が一番少ない．全肺葉で重症度が高いほど粒状影数が多く，特に上葉で顕著である ．

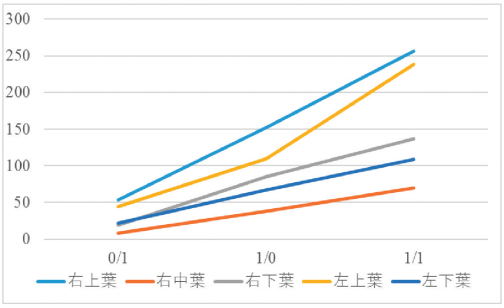

図 3　重症度と肺葉別の粒状影数

図 4 に重症度ごとの肺葉別粒状影の平均分布割合を示す．どの重症度でも右上葉が約 35%占めていた．一般的な肺葉別体積の割合は右上葉：20%，右中葉：10%，右下葉：25%，左上葉：25%，左下葉：20%である．このことから，右上葉の粒状影が多いことが分かる．重症度間で肺葉別の粒状影の分布割合に差は見られなかった．

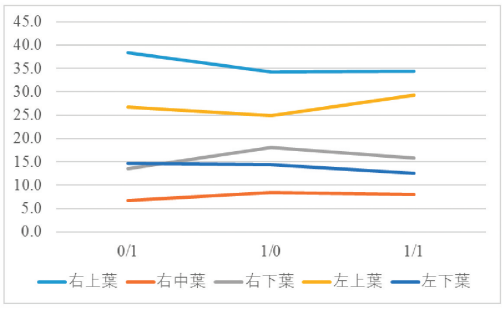

図 4　重症度と肺葉別の粒状影数の割合

表 3 に重症度別の肺葉粒状影数に有意差があるか解析した．全ての重症度間において上葉に有意差がある．

表 3　重症度別の肺葉粒状影数の比較評価

右上葉	0/1	1/0
1/0	0.00043	-
1/1	4.3×10^{-7}	0.0042
右中葉	**0/1**	**1/0**
1/0	0.055	-
1/1	0.0013	0.1617
右下葉	**0/1**	**1/0**
1/0	0.00542	-
1/1	0.00015	0.13791
左上葉	**0/1**	**1/0**
1/0	0.045	-
1/1	2.9×10^{-8}	3.9×10^{-5}
左下葉	**0/1**	**1/0**
1/0	0.051	-
1/1	0.0035	0.3046 (P<0.05)

また，重症度間で肺葉別の粒状影数の割合には有意差がなかった．

表 4 に粒状影数の割合が各肺葉間に有意差があるか解析した．右下葉と左下葉間以外に有意差があった．

これらのことからじん肺の重症度の評価には肺葉の粒状影数が重要であることが分かった．

表 4　肺葉粒状影数の割合の比較評価

	左下葉	左上葉	右下葉	右中葉
左上葉	7.3×10^{-8}	-	-	-
右下葉	1.0	2.4×10^{-6}	-	-
右中葉	0.01107	8.5×10^{-16}	0.00081	-
右上葉	2.0×10^{-16}	3.1×10^{-5}	2.0×10^{-16}	2.0×10^{-16} (P<0.05)

4. まとめ

3D U-Net を使用し，肺を葉別に 5 分割した．分割したデータを用いて，重症度別にじん肺の粒状影数と分布の割合について調べた．重症度が高いほど全肺葉で粒状影数が多く，特に上葉で顕著であった．重症度間で各肺葉の粒状影の分布割合に差はなかった．じん肺の重症度の評価には肺葉の粒状影数が重要であることが分かった．

今後の課題として，症例数の増加，重症度の定量的な評価法の構築がある．

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P3-1
3次元CT画像による3D-UNetを用いたじん肺症例の粒状影抽出

1）徳島大学大学院社会産業理工学研究部
2）川崎医科大学　北海道中央労災病院
3）岡山ろうさい病院
4）長崎大学
5）株式会社 医用科学研究所

松廣 幹雄[1)]、橋本 悠雅[1)]、鈴木 秀宣[1)]、河田 佳樹[1)]、大塚 義紀[2)]、岸本 卓巳[3)]、芦澤 和人[4)]、仁木 登[5)]

じん肺は，粉じんを肺に吸入することによって生じる職業性呼吸器疾患である．我国において毎年24万人前後の粉じん労働者がじん肺健康診断を受診している．じん肺の診断はX線写真を用いて行われ病変は軽度なものは粒状影，重度なものは不整形陰影が描出される．じん肺の病系は0型から第4型に分類され，それぞれの型でさらに3つに分類される．労災認定の境界となる第0型の0/1と第1型の1/0の区別が重要となる．3次元CT画像はX線写真に比べて正確に病変を評価することができるため高精度な診断が期待できる．3次元CT画像から3D-UNetによって高精度に粒状影を抽出する手法について述べる．本手法を様々な病型の症例に適用して有効性を示す．