Ann Agric Environ Med 2004, 11, 279–284

DIAGNOSTIC VALUE OF HIGH RESOLUTION COMPUTED TOMOGRAPHY IN THE ASSESSMENT OF NODULAR CHANGES IN PNEUMOCONIOSIS IN FOUNDRY WORKERS IN LUBLIN

Jerzy Mosiewicz[1], Wojciech Myśliński[1], Grażyna Złomaniec[2], Róża Czabak-Garbacz[3], Witold Krupski[2], Grzegorz Dzida[1]

[1]Department of Internal Diseases, Skubiszewski Medical University of Lublin, Poland
[2]Department of Radiology, Skubiszewski Medical University of Lublin, Poland
[3]Department of Human Physiology, Skubiszewski Medical University of Lublin, Poland

Mosiewicz J, Myśliński W, Złomaniec G, Czabak-Garbacz R, Krupski W, Dzida G: Diagnostic value of high resolution computed tomography in the assessment of nodular changes in pneumoconiosis in foundry workers in Lublin. *Ann Agric Environ Med* 2004, **11**, 279–284.

Abstract: The workers of an iron foundry were exposed to air pollution, which after some time of exposure results in lung fibrosis among some workers. The diagnosis of pneumoconiosis in workers of an iron foundry is based mainly on the radiological findings among workers exposed to the dust causing lung fibrosis. However, on radiograms many parenchymal structures overlap, which limits sensitivity and specificity to the method. Difficulties in accurate interpretation of conventional radiograms in silicosis also result from their relatively low resolution. The purpose of the present study was to assess the value and usefulness of high resolution computed tomography in the diagnostics of nodular changes in foundry workers' pneumoconiosis, compared to conventional radiography. The study group consisted of 64 iron foundry workers in whom silicosis had been recognized. The average age of the group was 51 years and the mean silica exposure time was 23 years. Chest radiograms with hard X-rays were taken at the maximal inspiration phase. For the HRCT examination the Siemens Somatom ART apparatus was used, equipped with a 512 × 512 pixels reconstruction matrix and a special programme for high resolution algorithm image reconstruction. In our material, consistency of results for conventional radiography and HRCT in revealing the presence of nodules was high. A statistically significant increase in detectability of intralobular nodules and peripheral nodules localized under the pleura was observed. The increase in detectability of cavernous, calcified nodules and those in the upper pulmonary fields obtained from computed tomography, however, was not statistically significant. High resolution computed tomography provides significant additional information in patients with foundry workers' pneumoconiosis.

Address for correspondence: Jerzy Mosiewicz, MD, PhD, Chair and Department of Internal Diseases, Skubiszewski Medical University of Lublin, Staszica 16, 20-081 Lublin. E-mail: jzmos@eskulap.am.lublin.pl

Key words: foundry workers' pneumoconiosis, high resolution computed tomography.

The workers of an iron foundry are exposed to air pollution containing ferric oxides, especially silica, which after some time of exposure results in lung fibrosis among some workers.

Received: 24 July 2004
Accepted: 24 September 2004

The diagnosis of pneumoconiosis in workers of an iron foundry is based on the criteria of the assessment of exposure to the dust causing lung fibrosis and on the radiological findings, according to the classification of the

International Labour Organization [11]. One of the most commonly encountered changes in the picture of simple pneumoconiosis are nodules. However, individual variable sensitivity to silica exposure and the individual variable response of the lungs to its presence hinder an early detection in the subclinical stage, as well as later prognosis of the disease. Therefore, new techniques of visualisation of the early changes which could especially make the diagnosis of pneumoconiosis at subclinical stages easier and the prognosis of the progression of the illness (due to the observation of the present changes) are necessary. Such techniques include high resolution computed tomography (HRCT), but its significance in patients with silicosis has not been definitively established in current literature. At present, HRCT is not accepted as a diagnostic tool for detection of the disease.

THE AIM OF THE PAPER

The paper aimed to assess the value and usefulness of high resolution computed tomography in the diagnostics of nodular changes in foundry workers' pneumoconiosis, compared to conventional radiography.

MATERIAL

The material comprised of a group of 64 patients employed at an iron foundry in whom silicosis had been recognized. The diagnosis was based on case history, long exposure to dust containing silica at the workplace, clinical assessment and the presence of radiographic changes. In most cases, silicosis of type p (59 cases) was found and in only 5 persons there were opacities classified as type q. In the examined group, males constituted 92.2%. The average age of the group was 51 years and ranged from 39–74 years (males) and from 45–49 years (women). Silica exposure time ranged from 12–40 years (mean 23 years).

STUDY METHODS

Chest radiograms with hard X-rays were taken at the maximal inspiration phase. The analysis of the number, extent and decantation of small opacities, which were assessed according to silicoses classification of the International Labour Organisation of 1980, was investigated.

For the HRCT examination the Siemens Somatom ART apparatus was used, was equipped with a 512 × 512 pixels reconstruction matrix and a special programme for high resolution algorithm image reconstruction. The thickness of layers was 2 mm and sections were performed every 10 mm. The width of the examined field was limited to 25 cm. Two window systems were used – pulmonary and supplementary – mediastinal. The width of the window ranged from 1200 to 1600 H.u. from –700 to –600 H.u. The following parameters of exposure were used: voltage 130 KV, intensity 150 mA.

Scanning time was 3 seconds. The number of sections depended on the intensity and localization of radiographic changes and other diagnostic indications. A scanning tomogram in P-A projection was carried out first and then sections in selected fields in which abnormalities were found. Most often, 7-8 sections were performed at 1 mm interspaces. In some cases the examination was carried out from apices of the lungs to the diaphragm, with 1 mm interspaces between layers. Sections on selected upper and medial levels of pulmonary fields were performed. If morphological features typical of silicosis were found on the first section at the level of bifurcation of the trachea, further examinations were usually not carried out. If the picture was normal or doubtful, additional sections half way between bifurcation of the trachea and apices of the lungs, as well as between bifurcation and apex of the right diaphragmatic dome were additionally carried out.

In the case of a lack of radiographic changes, preliminary sections were carried out at the level of the arch of the aorta, bifurcation of the trachea, 1 cm above the right diaphragmatic dome and at the hilus level. In some cases, for better visualization of segmental and subsegmental bronchi, as well as supradiaphragmatic regions, the circumvex was inclined by 20º towards the patient's head.

The distribution of changes was defined by relating their position to the pulmonary lobule. In the axial plane peripheral, the subpleural and central zone were distinguished. In selected cases magnification of the picture and three-dimensional reconstructions were used.

HRCT examination was performed both at the stage of maximal inspiration and expiration in patients lying prone on their backs. This was supplemented several times in the position on the stomach which enabled exclusion of condensation resulting from the action of hydrostatic mechanisms. The so-called gravitation effect may be responsible for a decrease in the volume and pneumatisation of parenchyma of the posterior parts of the lungs due to pressure. Examination in the prone position on the stomach allowed for the differentiation of oedematous or atelectatic changes from early fibrination of pulmonary tissue. Chest radiograms and CT scans were assessed by independent radiologists.

Statistical analysis. The obtained data was statistically analysed. Results were classified into one of the following 4 combinations:

- radiography + HRCT +: both techniques revealed a given symptom,
- radiography + HRCT -: the symptom was revealed only with radiography,
- radiography – HRCT +: the symptom was revealed only with HRCT technique,
- radiography – HRCT –: neither method revealed the symptom.

The frequency of individual combinations were expressed in percentages. The significance of the differences between percentages (and the significance of correlations) of both techniques were checked using χ^2 test. The power of the relation between both examined techniques was expressed with a power of relation coefficient r. In the study there was an assumed 5% risk of erroneous conclusion ($p<0.05$ was assumed as significant).

RESULTS

The test of correlation of both methods (χ^2 test) was done for nodular changes, calcified nodules and nodules conducted in upper fields (Tab. 1). For each of these symptoms, a highly significant correlation ($p<0.001$) of conventional radiography and HRCT was found. This accounted for a high percentage of consistent results, i.e. both techniques revealed or did not reveal a given symptom. This percentage amounted to 88% for nodules to 91% for nodules localized in the upper fields.

Inconsistent results can be of 2 kinds: HRCT does not confirm symptoms detected with radiography and detects symptoms that cannot be detected radiographically. In none of the 64 cases did radiography reveal cavernous, intralobular or peripheral nodules localized under the pleura (Tab. 2). These changes can only be visualized with HRCT examination.

Results listed in Table 3 account for a statistically significant increase of detectability of intralobular nodules and peripheral nodules localized under the pleura. Observed increase of detectability of cavernous, calcified nodules and those in the upper pulmonary fields, however, was not statistically significant.

Table 2. Radiologically undetectable symptoms or poorly detectable ones.

Symptom	Rtg			
	+	-	+%	-%
Cavernous nodules	0	64	0	100
Intralobular nodules	0	64	0	100
Peripheral subpleural nodules	0	64	0	100
Conglomerates	3	61	4.7	95.3
Rheumatic nodules	2	62	3.1	96.9

The presence of rheumatic nodules was revealed with radiography in only 2 patients and of conglomerates in 3 patients, which prevented carrying out a correlation test between the 2 techniques under study.

DISCUSSION

The basic method for recognizing silicosis in workers of an iron foundry is the conventional x-ray examination. However, on radiograms many parenchymal structures overlap, which limits sensitivity and specificity of the method in revealing subtle pulmonary changes. Difficulties in accurate interpretation of conventional radiograms in silicosis also result from their relatively low resolution. Conventional radiograms are assessed based on ILO classification, but this classification is not perfect since it does not take into account early intraparenchymatous

Table 1. Correlation between conventional radiography and HRCT in the assessment of nodular changes. Number (f) and percentage (%) of 4 combinations of both techniques in 64 patients. (R: conventional radiography, T: high resolution computed tomography). (+ stands for a present symptom, - an absent symptom).

Symptom	Statistics	R+ T+	R+ T-	R- T+	R- T-	Correlation			% of consistent R and T
						χ^2	r_p	p	
Nodules	f	48	1	7	8	20.94	+ 0.70	< 0.001	88
	%	75.0	1.6	10.9	12.5				
Calcified nodules	f	9	0	4	51	35.56	+ 0.85	< 0.001	94
	%	14.1	0	6.2	79.7				
Nodules in upper fields	f	52	1	5	6	20.81	+0.70	< 0.001	91
	%	81.3	1.6	7.8	9.4				

Table 3. Percentages of detected or not detected nodular changes by means of HRCT in patients with silicosis without symptoms in conventional radiography.

Symptom	R-	%T-w N (64)	Among R-		%T+ among R-	Significance	
			T-	T+		χ^2	P
Nodules	15	23.4	8	7	46.7	3.27	NS
Cavernous nodules	64	100	62	2	3.1	0.06	NS
Calcified nodules	55	85.9	51	4	7.3	0.29	NS
Intralobular nodules	64	100	16	48	75.0	36.00	<0.001
Peripheral subpleural nodules	64	100	34	30	46.9	14.06	<0.001
Nodules in upper fields	11	17.2	6	5	45.5	2.27	NS
Rheumatic nodules	62	96.9	52	0	0	0	NS

changes and does not fully reconstruct their extent. Nearly half of the field of a lung on a frontal radiogram is covered by the mediastinum and diaphragm, thus being inaccessible for assessment. Hence, a normal picture of conventional radiography in people exposed to dust does not exclude the presence of silicosis. In studies by Lamers *et al.*, about 10-16% of patients with intraparenchymatous diseases of the lungs showed a completely normal radiographic picture [13]. Conformity of radiologic diagnoses (made on the basis of ILO classification and Union Internationale Centre du Cancer) with histopathologic results in the case of diffuse pulmonary diseases were only 50-70% [16].

Due to individual sensitivity to dust, and connected with this, individually variable progression of pulmonary changes and their apparent regression with age in some cases, there is the need for techniques for their visualization, especially for early changes [2]. These would enable recognition at the subclinical stage and prognosing the course of disease. Long lasting clinical-radiological observations indicate that in some cases of silicosis constant progression of radiological changes occurs, concerning both the type and density of opacities. In other cases, relative stability of changes is observed in conventional radiography, or even their apparent regression. More precise assessment of morphological changes which occur in the early stages of pneumoconiosis perhaps allow us to better verify current opinions of the prognosis and the course of the disease.

Essential elements of the HRCT technique are: the use of thin, collomated sections (1-2 mm), algorithm of high spatial resolution, reconstructions in a limited field of visibility and short scanning period (3 seconds). Another advantage of the HRCT examination is the low dose of radiation, 6-12% lower than in the case of conventional computed tomography. A total dose during a multilevel examination is comparable to the dose used during a conventional radiogram [23].

The extent of silicosis in HRCT is determined by pulmonary fields with increased density corresponding to nodular opacities. In our material, consistency of results for conventional radiography and HRCT in revealing the presence of nodules was high (88%). However, the use of HRCT in the group of examined patients allowed for the detection of nodules in nearly 47% of such patients where radiography failed to detect anything. These were cavernous, calcified nodules, especially intralobular ones, as well as peripheral-subpleural and nodules localized in the upper pulmonary fields. The percentage of patients for whom the HRCT technique revealed nodules (invisible in conventional radiography) ranged from 3% (in the case of cavernous nodules) to 75% (in the case of intralobular nodules). Conventional radiography was unable to reveal cavernous, intralobular lobules and those localized under the pleura in any of the examined cases of silicosis.

Parenchymatous changes revealed in HRCT in conventional radiography were often invisible, poorly visible, or doubtful. HRCT revealed small opacities earlier than conventional radiograms and assessment of their concentration was more precise. HRCT sections more accurately and earlier detected small and multivocal opacities than radiograms. HRCT also allows assessment of the relationship of opacities to the pulmonary lobule. Visualisation of early and tiny nodular changes also resulted from reduced overlapping of parenchymatous structures.

According to Begin *et al.* [3], HRCT can reveal anthracotic changes before they appear on radiograms. This higher sensitivity of HRCT is connected with the possibility of visualizing changes on the level of the secondary lobule [22]. HRCT has revolutionized diagnostics of chronic infiltrative pulmonary diseases, revealing early changes, invisible on radiograms [6, 15, 21].

HRCT can show the presence of most nodules over 2-3 mm in diameter [7], although adjacent nodules to the hilus are more difficult to visualize. Nodules 3-6 mm in diameter are usually well visible.

In revealing small silicotic nodules, their number and extent, HRCT is more accurate than radiograms. Lee *et al.* [14] report that in 30% cases that lack anthracotic changes on radiograms, HRCT showed the presence of intraparenchymal micronodules with a diameter less than 7 mm. Remy-Jardin *et al.* [17] report that HRCT revealed 15% more nodular condensations, especially small ones with low condensation compared with conventional radiography. Elimination of the overlapping of parenchymatous structures in HRCT is facilitated by visualization of nodules without the necessity of subtraction. The assessment of the extent of dust disease changes, number of nodules and presence of consolidation is also more objective in HRCT. Gamsu *et al.* [8] estimate that sensitivity of HRCT is 24% higher than with conventional radiological examination. Also, Akira *et al.* [1], examining patients with type p silicosis (according to ILO classification) showed the usefulness in supplementing radiography with HRCT scans, which allowed a more precise classification of lesions.

HRCT is also useful in the assessment of the character of nodules, defining more accurately morphological features of the changes in size, density, shape, inner structure, presence of vessels in the nodule, calcifications, satellite changes, sharp and spicullary contours, lobular or a cavernous character in a necrotic nodule [14]. Nodules undergo the process of contraction and then form indistinct or irregular contours. They exhibit small heterogenic density with numerous, small branches of pulmonary vessels. The appearance of vesicular recovery in warty nodules makes it necessary to differentiate them from cystoid spaces. The heterogenic density of nodules is essential for differentiating them from vesicular cancer.

Bergin *et al.* [5] assessed nodular changes quantitatively from the first degree, corresponding with a small number of nodules, to the fourth degree, corresponding to consolidation fields. In the assessment of grading silicosis, degree 0 corresponded to the lack of nodules, degree I – a small number of nodules, with normal vascular picture, degree II – multiple not blurring nodules, with a partly obliterated vascular picture, degree III – blurring nodules, with a completely obliterated vascular picture, degree IV - blurring nodules on more than 2 sections, which corresponds to the diagnosis of massive fibrosis [4, 18]. Comparison of radiograms with HRCT shows supplementation of both techniques. HRCT proves useful in the detection of a small number of micronodules. In group 0 (acc. to conventional radiography), HRCT detects micronodules in 22%, group 0/1 in 45%, in 1/0 in 61%, in 1/1 in 67% patients. In all groups, micronodules were detected more often by HRCT when radiographic opacities were assessed as round ones (p,q). Besides, HRCT differentiates radiographic opacities which may correspond to bronchial distension or only emphysema [9].

Begin *et al.* [4] also found the presence of significant differences in average values for density of normal lungs with emphysema and intraparenchymatous fibrosis measured with computed tomography. Although an objective qualitative index of silicosis seems desirable, its formulation is hindered by technical problems for measurements of lung density – i.e. densitometry. The mean results of lung density measurements differ in the same patient, depending on stages of breathing. Furthermore, in progressive silicosis the density of the upper lobes is increased. The basis of measurements of density in silicosis had considerable differences from normal values. In other intraparenchymatous diseases, differences between normal and pathological pulmonary tissue are smaller. Consequently, today, visual assessment of HRCT pictures in silicosis is more useful than measurements of mean densities. Visual assessment of HRCT pictures in silicosis and classification of the dissemination of nodules according to the ILO scheme in conventional radiograms correlate well with each other, including the presented material.

Silicotic nodules in HRCT pictures have their evolution, side by side with the development of the disease fine, pin-like nodosity becoming more abundant. These spheric opacities are usually described as micronodules (diameter up to 3 mm) or masses over 20 mm. Identification of micronodules requires performing HRCT sections [20]. Privileged localization of micronodules is in the subpleural region. Such changes of this localization require differentiation with sarcoidosis and lymphangitis carcinomatosa [10]. Peripheral fields with increased density are typical lesions closely associated with the subpleural lymphatic system. Localization of pneumoconiotic changes in the upper lobes can be explained by physiologic principles of pulmonary lymphatic drainage.

Silicosis is caused by an inability to remove and eliminate dust particles; therefore, in the zone of handicapped lymphatic outflow damages are the greatest. The most extreme changes occur in the upper fields, especially from the rear. These upper and posterior localizations are well known [19]. The presence of subpleural micronodules in miners on radiograms without the presence of silicosis confirms secondary accumulation of the particle material due to delayed lymphatic drainage of the lungs. The system of granulomas in sarcoidosis is similar to absorbed particles in silicosis and is often referred to as perilymphatic. The presence of subpleural micronodules in smokers suggests an association with lymphatic drainage of the lungs. Subpleural lesions in anthracosis are identical with those in silicosis. Subpleural fields of increased density caused by micronodules are also defined as pseudoplaque. As a rule, the plaque type change and determines fibrous thickening of parietal pleura usually occurring in asbestosis.

HRCT provides significant additional information in patients with silicosis [12] and enables differentiation of potentially malignant alterations. It reveals stages of disease, blurring of nodules and development of conglomerates invisible on radiograms. Masses of conglomerates usually have an oval shape and irregular borders. There is also observable deformation of lung architecture and normal vascular anatomy. An essential symptom of massive fibrosis in HRCT are mass-like consolidations associated with apical parenchymatous cicatrisation and adjacent vesicular changes (irregular or cicatricial emphysema). Calcifications associated with masses of conglomerates often occur which usually contain small density necrotic fields.

CONCLUSIONS

- Results of high resolution computed tomography correlate well with results of conventional radiography in the assessment of nodular changes in silicosis of iron foundry workers.
- High resolution computed tomography enables significantly more frequent detection of nodular changes of small sizes, especially those localized under the pleura.

REFERENCES

1. Akira M, Higashihara T, Yokoyama K, Yamamoto S, Kita N, Morimoto S, Ikezoe J, Kozuka T: Radiographic type p pneumoconiosis. High-resolution CT. *Radiology* 1989, **171**, l17-123.

2. Begin R, Ostiguy G, Fillion R, Colman N: Computed tomography scan in the early detection of silicosis. *Am Rev Respir Dis* 1991, **144**, 697-705.

3. Begin R, 0stiguy G, Groleau S, Filion R: Computed tomographic scanning of the thorax in workers at risk of or with silicosis. *Semin Ultrasound CT & MR* 1990, **11**, 380-392.

4. Begin R, Bergeron D, Samson L, Boctor M, Cantin A: CT assessment of silicosis in exposed workers. *AJR* 1987, **148**, 509-514.

5. Bergin CJ, Muller NL, Vedal S, Chang-Yeung M: CT in silicosis: correlation with plain films and pulmonary function tests. *AJR* 1986, **146**, 477-483.

6. Bonelli FS, Hartman TE, Swensen SJ, Sherrick A: Accuracy of high-resolution CT in diagnosing lung diseases. *AJR* 1998, **170**, 1507-1512.

7. Galvin JR, Mori M, Stanford W: High resolution computed tomography and diffuse lung disease. *Curr Probl Diagn Radiol* 1992, **21**, 31-74.

8. Gamsu G: Computed tomography and high-resolution computed tomography of pneumoconioses. *J Occup Med* 1991, **33**, 794-796.

9. Gevenois PA, Pichot E, Dargent F, Dedeire S., Vande Weyer R, De Vuyst P: Low grade coal worker's pneumoconiosis. Comparison of CT and chest radiography. *Acta Radiol* 1994, **35**, 351-356.

10. Gevenois PA, Pichot E., Dargent F, Vande Weyer R, De Vuyst P: Tomodensitometrie des pneumoconiosis. *Ann Radiol Paris* 1994, **37**, 222-228.

11. International Labour Office. *Guidelines for the use of ILO, International Classification of Pneumoconiosis.* Revised Ed. 1980. Occupational Safety and Health Series No 22, Genova 1980.

12. Kraus T, Raithel HJ, Hering KG: Evaluation and classification of high-resolution computed tomographic findings in patients with pneumoconiosis. *Int Arch Occup Environ Health* 1996, **68**, 249-254.

13. Lamers RJ, Schins RP, Wouters EF, van Engelshoven JM: High-resolution computed tomography of the lungs in coal miners' with a normal chest radiograph. *Exp Lung Res* 1994, **20**, 411-419.

14. Lee KS, Kim TS, Han J, Hwang JH, Yoon JH, Kim Y, Yoo SY: Diffuse micronodular lung disease: HRCT and pathologic findings. *J Comput Assist Tomogr* 1999, **23**, 99-106.

15. Meziane MA, Hruban RH, Zerhouni EA, Wheeler PS, Khouri NF, Fishman EK, Hutchins GM, Siegelman SS: High-resolution CT of the lung parenchyma with pathologic correlation. *Radiographics* 1988, **8**, 27-54.

16. Muller NL, Mayo JR, Lentle BC: Imaging of diffuse lung diseases. Past, present and future. *Radiol Clin North Am* 1991, **29**, 1115-1121.

17. Remy-Jardin M., Beuscart R., Sault MC, Marquette CH, Remy J: Subpleural micronodules in diffuse infiltrative lung diseases. Evaluation with thin-section CT scans. *Radiology* 1990, **177**, 133-139.

18. Remy-Jardin M, Degreef JM, Beuscart R, Voisin C, Remy J: Coal worker's pneumoconiosis: CT assessment in exposed worker's and correlation with radiographic findings. *Radiology* 1990, **177**, 363-371.

19. Remy-Jardin M, Remy J, Farre I, Marguette CH: Computed tomographic evaluation of silicosis and coal worker's pneumoconiosis. *Radiol Clin North Am* 1992, **30**, 1155-1176.

20. Remy-Jardin M, Remy J, Giraud F, Marquette CH: Pulmonary nodules: detection with thick-section spiral CT versus conventional CT. *Radiology* 1993, **187**, 513-520.

21. Stern A: *High-resolution CT of the chest.* Lippincott Williams & Wilkins. Philadelphia 2000.

22. Webb WR: High-resolution lung computed tomography. Normal anatomic and pathologic findings. *Radiol Clin North Am* 1991, **29**, 1051-1063.

23. Zwirevich CV, Mayo JR, Muller NL: Low-dose high-resolution CT of the lung parenchyma. *Radiology* 1991, **180**, 413-417.