



Using volume-time curves with real-time three-dimensional echocardiography to analyze right ventricular function in patients with pneumoconiosis

D.M. Wei¹, Y. Ding² and W. He¹

¹Department of Ultrasound, Beijing Tian Tan Hospital, Capital Medical University, Beijing, China

²Department of Radiology, Beijing Chao-Yang Hospital, Capital Medical University, Beijing, China

Corresponding author: W. He

E-mail: hewen201319@163.com

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ABSTRACT. We evaluated right ventricular function in patients with pneumoconiosis using real-time three-dimensional echocardiography (RT3DE). A total of 80 consecutive patients were prospectively recruited, 44 of whom were diagnosed with pneumoconiosis, and the remaining 36 age- and gender-matched healthy volunteers served as the control group. All patients underwent both 2D and 3DE. The tricuspid regurgitation pressure (TRPG), right ventricular anterior wall thickness and range of motion, right ventricular posterior wall thickness and range of motion, right ventricular end-diastolic volume, right ventricular end-systolic volume, and right ventricular ejection fraction (RVEF) were measured. The RVEF of healthy volunteers ranged from 50 to 78%, while the RVEF of pneumoconiosis patients ranged from 29 to 73%. TRPG influenced RVEF by 77.3% ($P = 0.006$) and showed a negative correlation ($r = -0.643$, $P < 0.01$). Volume-time curves (VTC) of patients

with pneumoconiosis showed more troughs (low stroke volumes) than the VTCs of normal subjects. Evaluation of right ventricular function in patients with pneumoconiosis using RT3DE can provide additional clinical information.

Key words: Right ventricular function; Volume-time curves; Real-time three-dimensional echocardiography; Pneumoconiosis

INTRODUCTION

Scientific advancements in the study of cardiac structure and function have led to increased attention on evaluation of right ventricular function (Di Salvo et al., 1995; Rigolin et al., 1995). Assessment of the degree of volume and pressure load caused by various diseases on right ventricular function (Heusch et al., 2006; Kjaergaard et al., 2006) is extremely important when making treatment choices and predicting prognosis. In two-dimensional echocardiography (2DE), right ventricular function is assumed from the left ventricle based on geometry, and then calculated from a formula for the left ventricle, so this method is prone to large errors. The main reason behind these errors is the fact that the right ventricle is an irregular, crescent-shaped structure, featuring many trabeculations, which form an irregular endocardial border. Furthermore, the inflow and outflow tracts do not exist in the same plane and are quite different in shape between the right and left ventricle. Considering these factors, processes ignoring the inflow and outflow tracts are not rigorous enough in their methodologies.

Previous studies used magnetic resonance imaging (MRI) and X-ray computed tomography (CT) on healthy individuals and patients with heart disease to evaluate ventricular volume, stroke volume, and ejection fraction (EF). MRI measurements of stroke volume and end-diastolic ventricular volume tend to underestimate the values and lack consistency (Rajappan et al., 2002), while EF can be overestimated by CT (Utsunomiya et al., 2006). Three-dimensional echocardiography (3DE) (Ahmad, 2001; Utsunomiya et al., 2006), which has undergone rapid development in recent years, is based on the actual morphology of the heart chambers and involves acquiring multi-planar images and digitally reconstructing them using 3D technology. Without a geometric model of the left ventricle, real-time 3DE (RT3DE) can display the spatial structure of the heart chamber and measure data to form volume-time curves. RT3DE can overcome many limitations of 2DE: It not only enables observation of the morphology of the heart chambers but also assesses right ventricular stroke output and right ventricular volume parameters (Jiang et al., 1994; Muller et al., 2002; Nesser et al., 2006). The 3D volume is set to a fan angle of $60^\circ \times 60^\circ$ in patients with heart enlargement. The probe position must be changed to acquire the full range of the ventricular endometrial into the fan angle to avoid the loss of some portion of the volume (Endo et al., 2006).

Pneumoconiosis mainly changes the pathology of emphysema and pulmonary fibrosis associated with the final stages of chronic pulmonary heart diseases. Moreover, right ventricular function is affected by the gradual increase in pulmonary artery pressure. In this study, changes in right ventricular function were observed by RT3DE in patients with pneumoconiosis.

MATERIAL AND METHODS

General information

The study included 36 healthy volunteers and 44 patients diagnosed with pneumoconiosis by an occupational disease diagnosis appraisal committee. Their ages ranged from 23 to 83 years, with a mean age of 57 ± 16 years. The healthy volunteers showed normal findings on physical examination, electrocardiography (ECG), and routine echocardiography or showed only physiological valve regurgitation. Radiographs or CT images for pneumoconiosis staging and a history of dust exposure were recorded for patients with pneumoconiosis. All 44 patients signed a consent form before undergoing radiography or CT imaging. The exclusion criteria included atrial fibrillation and pulmonary embolism. The use of clinical data was approved by the Hospital Ethics Committee.

Equipment

A Philips IE33 echocardiography instrument, which is a first-generation RT3D imaging transducer (2.5 or 3.5 MHz), was used. It consists of 256 non-simultaneously firing elements in a matrix that can be activated simultaneously to generate a pyramidal volume in $60^\circ \times 60^\circ$ during a single heartbeat.

Research methods

Image acquisition

Subjects were placed in a left lateral position and monitored by synchronous ECG, after which the images were acquired. The imaging was visualized clearly in an apical 4-chamber view and a parasternal 4-chamber view; the right ventricle was placed at the center of the sampling area, and the gain and contrast were adjusted to clearly show the right ventricle and its intima. After full-volume imaging was initiated and the 3D image capture button pressed, pyramid-like full-volume 3D images were produced in a wide angle of $60^\circ \times 60^\circ$. After this acquisition, the subjects were asked to hold their breath at the end of expiration to decrease unavoidable artifacts, and the images were stored in the instrument for analysis.

Using color Doppler and M-mode echocardiography chart records, the tricuspid regurgitation pressure (TRPG), right ventricular anterior wall thickness and range of motion (TH_1 , M_1), and right ventricular posterior wall thickness and range of motion (TH_2 , M_2) were measured.

Image analysis

The QLAB 3DQ Adv measurement software was used to analyze right ventricular function. Based on the end-diastolic and end-systolic values from the ECG, the endocardial border of the tricuspid annulus and right ventricular apex were marked, and the software

automatically drew an outline of the right ventricular intima. The next step was to select a sequence to analyze the stored images by frames/s. Ultimately, we obtained data such as the right ventricular end-diastolic volume, right ventricular end-systolic volume, right ventricular ejection fraction (RVEF), and volume-time curve (VTC). In the VTCs (left ventricular VTC), the peak indicates the ventricular end-diastolic volume, and the trough indicates the end-systolic ventricular volume. It also contains information about the heart ventricular volume over 4 cardiac cycles.

Statistical analysis

The SPSS version 11.0 software was used for the analysis, and the data are reported as means \pm standard deviation for normally distributed values. RVEF and tricuspid regurgitation pressure (TR) were compared using a 2-sample *t*-test, multi-factor analysis of variance, and multiple correlation analysis. The cut-off value for significance was set at 0.05.

RESULTS

Staging of patients with pneumoconiosis by radiography

Among the 44 pneumoconiosis patients, 18 cases were classified as phase I (22.5%), 19 phase II (23.8%), and the remaining 7 cases (8.8%), phase III. The range of dust exposure history was less than 1 year to 39 years. Twenty-eight cases showed a TRPG \leq 25 mmHg, while the other 16 cases showed a TRPG \geq 26 mmHg. The TH₁ and TH₂ values showed significant differences ($P < 0.01$) between the pneumoconiosis patients and healthy subjects, but not their M₁ or M₂ values ($P > 0.05$) (Table 1).

In this study, the RVEF values of healthy volunteers ranged from 50 to 78%, and those of pneumoconiosis patients between 29 and 73% (Table 2).

After multi-factor analysis of variance, we found that TRPG had an influence on RVEF amounting to 77.3%, with a significant difference ($P = 0.006$), but no significant difference was observed in RVEF values from a history of dust exposure or imaging stage ($P > 0.05$). TR and RVEF showed a negative correlation in a multivariate analysis [$r = -0.643$ (<0.01)].

Ejection fraction (EF) was found to be decreased and TRPG, significantly increased in 2 patients, but their history of dust exposure and pneumoconiosis stage were significantly different (see Figures 1-6).

From the extent of the TRPG, we attempted to divide the pneumoconiosis patients into 2 subgroups: pressure-compensated (subgroup A₁, TRPG $<$ 26 mmHg) and pressure-decompensated (subgroup A₂, TRPG \geq 26 mmHg) subgroups. In subgroup A₁, there were 28 cases, whose RVEF ranged from 50 to 71%. In the other 16 cases in subgroup A₂, the RVEF varied between 29 and 73%.

According to the RVEF, we categorized the pneumoconiosis patients into function compensated (subgroups B₁, RVEF \geq 50%) and decompensated (subgroup B₂, RVEF $<$ 50%) groups. There were 35 cases with TRPG below 47 mmHg in subgroup B₁ and 9 cases with TRPG between 45 and 97 mmHg in subgroup B₂.

Table 1. Right ventricular wall thickness and mean and range of motion (in mm).

Group	Cases	TH ₁	M ₁	TH ₂	M ₂
Healthy	36	3.27 ± 0.65	6.23 ± 0.99	3.81 ± 0.66	8.02 ± 1.73
Pneumoconiosis	44	4.07 ± 0.91	6.58 ± 2.54	5.46 ± 1.43	7.39 ± 1.79
P		0.000	0.433	0.000	0.114

TH₁ = right ventricular anterior wall thickness; M₁ = right ventricular anterior wall range of motion; TH₂ = right ventricular posterior wall thickness; M₂ = right ventricular posterior wall range of motion.

Table 2. Right ventricular volume and mean EF and TR values on three-dimensional ultrasonography.

Group	TRPG (mmHg)	RVEDV (mL)	RVESV (mL)	RVEF
Healthy	2.33 ± 6.75	25.68 ± 11.42	9.25 ± 5.22	64% ± 8%
Pneumoconiosis	25.27 ± 24.97	40.10 ± 22.77	18.65 ± 14.57	55% ± 11%
P	0.000	0.001	0.000	0.000

TRPG = tricuspid regurgitation pressure; RVEDV = right ventricular end-diastolic volume; RVESV = right ventricular end-systolic volume; RVEF = right ventricular ejection fraction.

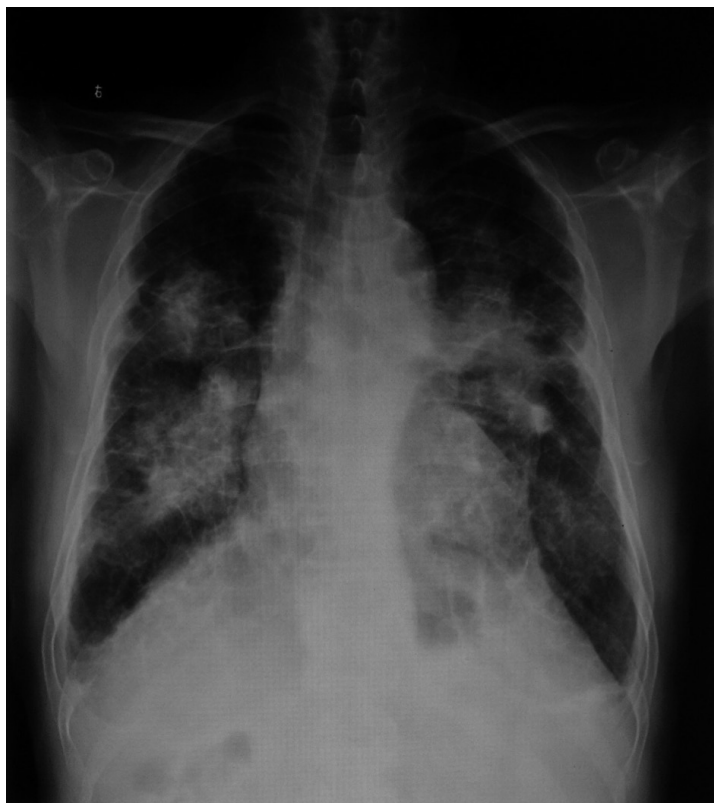


Figure 1. Patient: A 70-year-old man with a history of 20 years of dust exposure. The radiograph shows 2 markings of weight gain and small nodules in both lungs in oval and irregular dense shadow; part of the boundary is clear, multiple shadowy streaks are visible, and cystoid translucent film is present. The diagnosis was phase III pneumoconiosis.

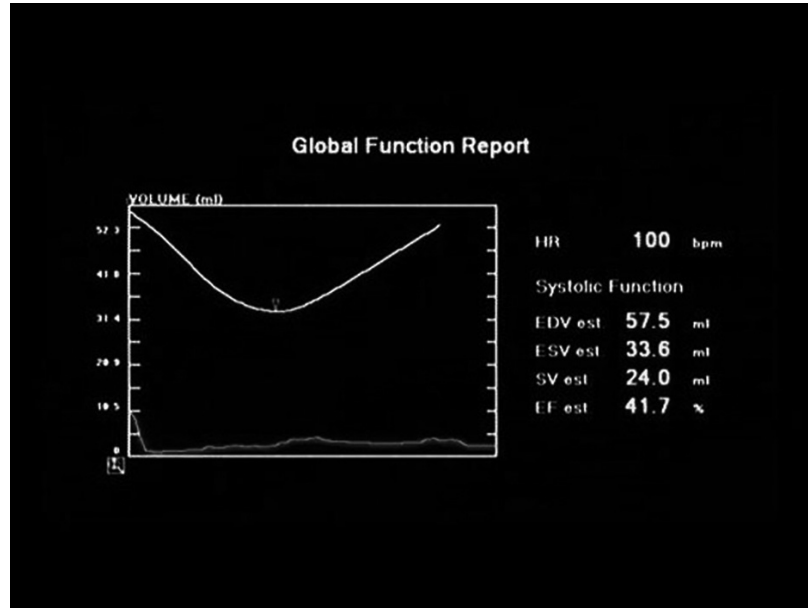


Figure 2. Real-time three-dimensional echocardiographic volume-time curve image of the same patient in Figure 1 shows an ejection fraction of 41.7%.



Figure 3. Two-dimensional color Doppler sonogram of the same patient in Figure 1 shows right heart increase and mild regurgitation of the tricuspid valve (the tricuspid regurgitation pressure was 72 mmHg).



Figure 4. Patient: An 82-year-old man with a history of 33 years of dust exposure. Radiographic image pairs show heavy markings, disorders, dual lung fields with multiple fiber cable of the shadow, partial fusion of the reticular nodules, scattered calcification, double opacities in the lung fields, visible lumps on the sides of the apex pairs, step down by degrees increased, and the left lung door's lymph node calcification. The diagnosis was phase III pneumoconiosis.

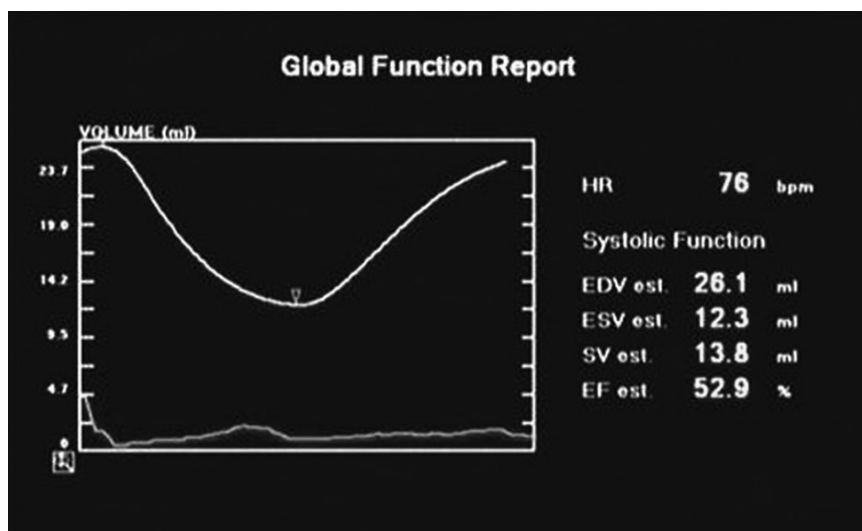


Figure 5. Real-time three-dimensional echocardiographic volume-time curve image of the same patient in Figure 4 shows an ejection fraction of 52.9%.

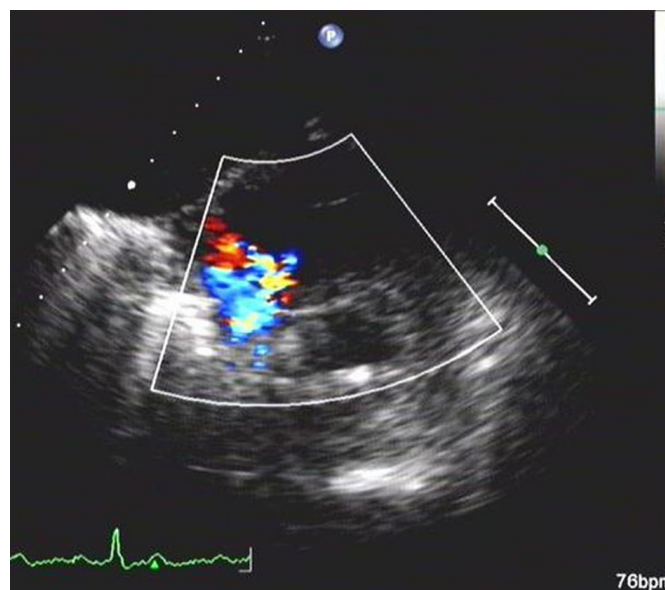


Figure 6. Two-dimensional color Doppler sonogram of the same patient in Figure 4 shows mild regurgitation of the tricuspid valve (the tricuspid regurgitation pressure was 40 mmHg).

DISCUSSION

Pneumoconiosis is an occupational lung disease characterized by chronic inflammation and fibrosis caused by the inhalation of mineral dust or metal. According to the diagnostic criteria formulated by the Code of Occupational Disease Prevention of the People's Republic of China, the diagnosis of pneumoconiosis involves an occupational history of dust exposure, respiratory symptoms and signs, and staging by radiography; however, right heart hemodynamic changes secondary to pulmonary fibrosis are not mentioned. This study focused on right ventricular function changes in different stages of pneumoconiosis. It was found that a history of dust exposure and radiography staging are not enough to reflect changes in right ventricular function. Interestingly, TRPG had an influence on RVEF of 77.3% ($P = 0.006$); RVEF tends to decrease with an increase in TRPG, showing a negative correlation. Right ventricular pressure load affected the volume load. An increase in right ventricular pressure load leads to right ventricular compensatory hypertrophy. An enhancement in right ventricular volume load results in significant morphological changes to the right ventricle. Significant differences were found in TH_1 , TH_2 , TRPG, EF, and right ventricular volume between pneumoconiosis patients and healthy subjects. These changes of ultrasonography are similar to pulmonary heart disease of other causes. The RVEF is the main indicator of right ventricular function. Owing to the wide use of RT3D ultrasonography in recent years, more attention has been paid to the right ventricular configuration and its cardiac output measurements (Jiang et al., 1994; Endo et al., 2006; Nesser et al., 2006). Researchers (Yan et al., 1995) discovered that the RVEF of patients with pulmonary heart disease was less than that of healthy subjects through 3D ultrasonography. In this study, the lowest RVEF observed was 29% among the pneumoconiosis patients. After a series of changes in the right heart from advancing pulmonary artery pressure, right

ventricular systolic and diastolic functions deteriorate (Hao et al., 1999). The present study used TRPG to determine the changes in pulmonary artery pressure, while Arcasoy et al. (2003) showed that the correlation coefficient between ultrasonography and right heart catheterization to measure pulmonary artery systolic pressure was 0.69, and reported the sensitivity of ultrasonography as 85%, with a specificity of 55%. In normal left ventricular VTCs (Zeidan et al., 2003), the deeper the trough the greater the stroke volume and the greater the difference between end-diastolic and end-systolic volume, which is reflected by the heart effectively pumping out more blood. In general, the right ventricle acts only as a channel, but from the view of the right ventricle VTCs, the right ventricle also plays a part in the pumping of blood. Previous studies suggested that right ventricular systolic function was reduced in the compensatory stage of pulmonary heart disease (Liu et al., 2008). In our study, the RVEF of subgroup A₁ was still in the normal range; while in subgroup A₂, the RVEF ranged from normal to significantly reduced. The TRPG was also mildly elevated in subgroup B₁, and the TRPG of subgroup B₂ showed mild to severe elevation. This implies that the evaluation of the function of the right heart without TRPG and RVEF is not comprehensive. When TRPG exists in the normal range (TRPG < 26 mmHg), the RVEF is normal. When the RVEF is reduced (<50%), the TRPG varied slightly or was severely elevated. However, there were variations between pressure and function compensations when the TRPG was elevated (≥26 mmHg) and when RVEF was increased (≥50%). In this study, the planes of the apical and parasternal 4-chamber heart were used in the methodology, including the right ventricular inflow tract (tricuspid valve annulus) while excluding the right ventricular outflow tract below the pulmonary valve. Researchers believe that the diameter of the right ventricular inflow tract changes significantly during the systolic and diastolic stages, which have a major influence on the right ventricular stroke volume. In contrast, the right ventricular outflow tract (from the ventricle to the pulmonary valve) is a uniform tubular funnel and has minor variations so that the VTC is not affected. The only changes are that the right ventricular end-diastolic volume and end-systolic volume are slightly smaller. Overall, the hemodynamics of the right heart in pneumoconiosis is variable. RT3DE is an option in determining critical conditions.

Conflicts of interest

The authors declare that they have no conflict of interest.

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