# Exercise-Induced Electrocardiographic Changes in Patients with Chronic Respiratory Diseases: Differential Diagnosis by $^{99m}$Tc-Tetrofosmin SPECT

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Evaluation of possible cardiac complications is essential for safe and effective respiratory rehabilitation of patients with chronic respiratory diseases (CRDs). The aim of this study is to clarify the pathophysiology of electrocardiographic (ECG) changes during exercise and the prevalence of coronary artery disease (CAD) in CRD patients without a history of myocardial ischemia. **Methods:** We studied 42 CRD patients with exercise-induced ST depression by cardiopulmonary exercise testing (CPET). They were selected from 249 consecutive CRD patients without any history of CAD who underwent CPET between January 1999 and December 2001. Thirty-three patients without respiratory diseases who had positive ST depression during exercise were selected as disease control subjects. Exercise myocardial SPECT was performed to evaluate myocardial ischemia and right ventricular (RV) overload as measured by increased RV uptake. **Results:** Among the 249 consecutive CRD patients without any history of CAD, positive ST depression during exercise was found in 42 (16.9%). Only 2 of the 42 patients (4.8%) had an ST depression other than in II, III, or aV$_F$ leads. The incidence of myocardial ischemia by perfusion SPECT was significantly lower in CRD patients (26.2%) than in disease control subjects (78.8%). The most common finding in the CRD patients during exercise was RV overload but without ischemia (26 cases; 61.9%). Ischemia was found in 11 patients (26.2%), with 10 of these patients also having RV overload. Neither ischemia nor RV overload was found in 5 patients (11.9%); these patients were eventually diagnosed as normal. **Conclusion:** The incidence of myocardial ischemia as determined by perfusion SPECT was low in CRD patients with positive exercise-induced ECG changes. On the other hand, RV overload was observed in most such cases. Cardiac perfusion SPECT is a useful technique to evaluate cardiac ischemia and RV overload simultaneously. CPET with 12-lead ECG monitoring is necessary in CRD patients before respiratory rehabilitation. Further examination for ischemia should be done if positive ST depression is found.

**Key Words:** chronic respiratory disease; cardiopulmonary exercise testing; myocardial perfusion SPECT; right heart overload; respiratory rehabilitation

**J Nucl Med 2003; 44:325–330**

Cardiopulmonary exercise testing (CPET) is useful in evaluating the ability of the cardiovascular and ventilatory systems and can determine the relative extent of cardiac, ventilatory, or muscular disturbance (*1*). Since 1989, we have administered CPET to patients with chronic respiratory diseases (CRDs) and have used the results to select the intensity of individual respiratory rehabilitation programs and the range of activity permitted in daily life. We have noticed exercise-induced ST depression on CPET in patients who did not exhibit symptoms and who had no history of coronary artery disease (CAD). It has been widely postulated that patients with chronic obstructive pulmonary disease (COPD) have a high prevalence of CAD due to a history of smoking, which is commonly recognized as a risk factor for CAD (*2*).

Exercise training, especially lower extremity training, proved to be effective for COPD patients in improving exercise tolerance (*3*). Such exercise training is widely practiced as a part of respiratory rehabilitation. If the prevalence of asymptomatic myocardial ischemia is high in CRD patients, an evaluation of CAD by eliciting a history of chest symptoms is meaningless. High-intensity exercise training may induce myocardial ischemia, placing the patient in jeopardy. An accurate diagnosis of ischemic complications is essential for safe and effective rehabilitation.

Received Jul. 8, 2002; revision accepted Oct. 29, 2002.

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On the other hand, right heart overload or right ventricular (RV) hypertrophy is a common phenomenon in CRD. The existence of cor pulmonale indicates a poor prognosis in COPD (*4*). Hypertrophy and increase of blood flow to the RV during exercise may influence the electric potential of the myocardium, but there is no evidence that they lead to exercise-induced ST depression.

Exercise-induced electrocardiographic (ECG) changes in patients with CRD have not been evaluated in detail. The aim of this study was to clarify, using myocardial perfusion SPECT, the pathophysiology of ECG changes during exercise and the prevalence of CAD in patients with CRD without any history of myocardial ischemia.

## MATERIALS AND METHODS

### Subjects

CPET was performed on 298 consecutive CRD patients at Toneyama National Hospital between January 1999 and December 2001. CPET was performed on a treadmill (Aeromill 2000; Nihon Koden, Tokyo, Japan) with progressive increments in 3-min stages according to a modified Sheffield protocol under continuous monitoring of a 12-lead electrocardiogram, blood pressure, and breath-by-breath expired gas. The exercise was stopped when the subject experienced intolerable symptoms, such as breathlessness, or when the electrocardiogram indicated that the criteria for ending the test were met (*5*). A positive response on electrocardiography was considered to be ≥1 mm of horizontal or downsloping ST depression in 3 consecutive beats compared with those of the electrocardiogram at rest. An upsloping ST depression of ≥1.5 mm below the baseline at 0.08 s after the J point was considered positive (*6*). All of the patients who underwent CPET had obstructive, restrictive, or combined respiratory dysfunction determined by pulmonary function tests and were in stable condition. Eighteen patients were excluded because of known CAD—that is, a history of acute myocardial infarction with both ECG and laboratory confirmation, history of coronary intervention, or evidence of significant coronary stenosis by coronary arteriography. Thirty-one patients with complete right or left bundle branch block at rest were also excluded because a false-positive finding for cardiac ischemia is likely in such patients (*7,8*). Of the remaining 249 cases, all of the 42 patients with exercise-induced ST changes were selected for study (Fig. 1).

Thirty-three patients with symptoms supporting the presence of CAD but without respiratory diseases who were proven to have positive ECG changes including the II, III, and aV$_F$ leads during exercise were selected as disease control subjects. All had normal chest radiographic findings, no history of respiratory diseases, and no symptoms of cough, sputum, wheeze, or dyspnea. Informed consent was obtained from all patients before CPET and SPECT.

### $^{99m}$Tc-Tetrofosmin SPECT

Forty-two patients and 33 disease control subjects underwent myocardial perfusion SPECT with exercise testing in an upright position on a bicycle ergometer. The initial load and incremental degree for CRD patients were decided individually on the basis of results of CPET. The initial load was 10 or 20 W, with increments of between 10 and 20 W every 2 min. For the disease control subjects, the exercise test was done with an initial 50-W load and 25-W/2-min consecutive increments. CRD patients were requested to attempt to pedal until the heart rate reached the maximum rate for CPET. One minute before stopping the test, 296 MBq $^{99m}$Tc-tetrofosmin (Nihon Mediphysics, Nishinomiya, Japan) were injected intravenously. For the at-rest study, 592 MBq $^{99m}$Tc-tetrofosmin were administered 4 h after the acquisition of exercise images. Acquisition was performed 30 min after injection with 180° data collection by 6° steps of 30 s using an SNC-510R scintillation camera (Shimadzu, Tokyo, Japan). Images were reconstructed containing the RV, and short-axis, horizontal long-axis, and vertical long-axis sections were obtained according to current recommendations (*9*). The SPECT image was considered positive when there was a mild-to-severe defect in at least 2 or 3 consecutive tomographic sections of the same axis, with reversibility at rest. RV overload was diagnosed when the RV wall could be clearly visualized at the midventricular level of short-axis sections. A square region of interest (ROI) of 2 × 2 pixels was placed over the center of the anterior, lateral, inferior, septal, and RV free walls at the midventricular level of the short-axis tomograph. The RV/LV ratio (where LV = left ventricular) was defined as the ratio of ROI counts in the RV to those of the sum of anterior, lateral, inferior, and septal walls.

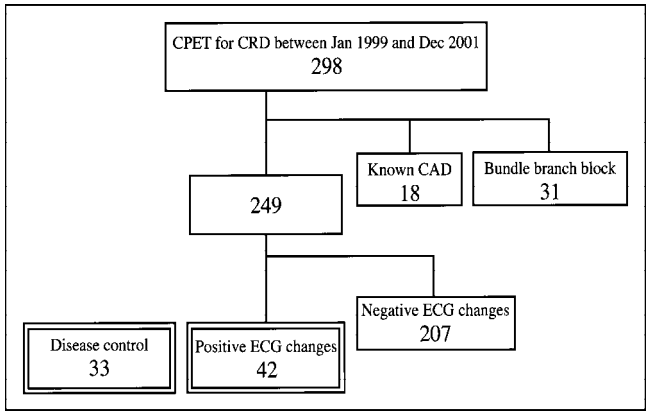


**FIGURE 1.** Patient recruitment. Only those who had no history of CAD, no sign of bundle branch block at rest, and positive exercise-induced ST depression, including II, III, and aV$_F$ leads, were recruited.

### Statistical Analysis

Data are expressed as mean ± SD. Prevalence was compared by a $\chi^2$ test. Data from quantitative analysis were evaluated by the Student *t* test. $P < 0.05$ was deemed statistically significant.

## RESULTS

General clinical characteristics and results of exercise testing are summarized in Table 1. Neither maximum heart rate nor the double product differed between the 2 methods of exercise, treadmill in CPET and ergometer in myocardial perfusion SPECT, in the CRD patients. The same degree of ST depression appeared during ergometer exercise as in CPET in all of the CRD patients. Hypoxemia during exercise (oxygen saturation as measured by pulse oximetry < 90%) was seen in 19 CRD patients (45.2%) but in none of the disease control subjects.

Figure 2 shows examples of myocardial perfusion SPECT. Increased uptake in the RV is seen in Figure 2A

**TABLE 1**
Clinical Characteristics

| Characteristic | CRD patients | Disease control subjects |
|---|---|---|
| *n* | 42 | 33 |
| Sex (M/F) | 35/7 | 24/9 |
| Age (y) | 68.1 ± 7.7 | 65.1 ± 11.1 |
| Height (cm) | 161 ± 8 | 159 ± 7 |
| Weight (kg) | 53.9 ± 10.3 | 60.5 ± 9.4* |
| Origin of lung disease (%) | | |
| COPD | 19 (45.2) | — |
| Tuberculosis sequela | 14 (33.3) | — |
| IIP | 2 (5.0) | — |
| Other† | 7 (17.5) | — |
| Risk factor (%) | | |
| Hypertension | 23 (54.8) | 19 (57.6) |
| Hyperlipidemia | 9 (22.5) | 11 (33.3) |
| Diabetes mellitus | 7 (16.7) | 11 (33.3) |
| Smoking | 32 (76.2) | 16 (48.5)* |
| Pulmonary function test | | Not done |
| VC (L) | 2.33 ± 0.89 | — |
| $FEV_1$ (L) | 1.33 ± 0.57 | — |
| $D_{LCO}$ (%) | 67.4 ± 32.7 | — |
| CPET by treadmill‡ | | Not done |
| $V_{O_2}$ (mL/kg/min) | 17.5 ± 4.9 | — |
| $Pa_{O_2}$ (mm Hg) | 61.6 ± 13.5 | — |
| HR/THR (%) | 86.6 ± 14.4 | — |
| Double product | 25,566 ± 6,281 | — |
| Myocardial perfusion imaging by upright ergometer‡ | | |
| HR/THR | 85.8 ± 13.8 | 98.3 ± 22.5* |
| Double product | 24,828 ± 6,331 | 30,384 ± 7,255* |

*$P < 0.05$.

†Origins of lung disease in patients designated as Other were post lung cancer surgery (2 patients), pneumoconiosis (2 patients), bronchiectasis (1 patient), pyothorax (1 patient), and giant bulla (1 patient).

‡At peak exercise.

IIP = idiopathic interstitial pneumonia; VC = vital capacity; $FEV_1$ = forced expiratory volume in 1 s; $D_{LCO}$ = diffusing capacity of lung for carbon monoxide; $V_{O_2}$ = volume of oxygen; $Pa_{O_2}$ = partial pressure of oxygen, arterial; HR/THR = heart rate/target heart rate.

Data are presented as mean ± SD or % of patients.

(RV overload during exercise) in comparison with Figure 2B (typical perfusion ischemia). Qualitative analysis showed that the prevalence of positive findings for ischemia in CRD patients was significantly lower (26.2%) than that in disease control subjects (78.8%; $P < 0.01$) and that the prevalence of RV overload was significantly higher in CRD patients (85.7%) than that in control subjects (39.4%; $P < 0.01$). With regard to the relationship between left ventricular perfusion ischemia and RV overload in patients with CRD, those patients with RV overload during exercise but without ischemia comprised the most common group (26 cases; 61.9%) (Fig. 3). Of the 11 patients who were revealed to have perfusion ischemia, 10 had RV overload and 1 patient had only myocardial ischemia. All 5 patients

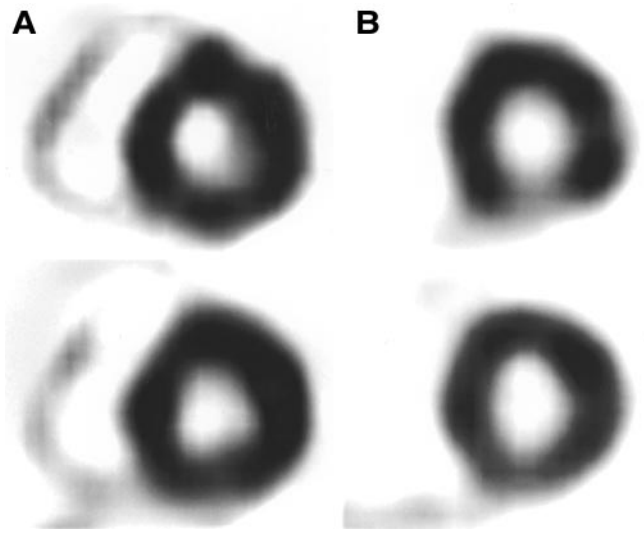


**FIGURE 2.** Midventricular short-axis imaging of representative CRD patients with RV overload (A) and perfusion ischemia (B). (A) Visualization and dilatation of RV both at rest (bottom panel) and during exercise (top panel). RV/LV ratio was greater during exercise than at rest (11.1% and 8.9%, respectively). (B) Typical perfusion ischemia in inferior wall during exercise (top panel) and normal perfusion at rest (bottom panel). RV could not be visualized in either image.

(11.9%) for whom there were no findings of ischemia or RV overload were diagnosed as normal.

Quantitative analysis of the RV/LV ratio revealed these ratios to be significantly higher in CRD patients than in disease control subjects both at rest (9.7 ± 3.0 vs. 7.6 ± 2.9) and during exercise (10.8 ± 1.9 vs. 8.2 ± 2.8). In CRD patients, the increase of the ratio during exercise was significant, whereas it was not significant in disease control subjects (Fig. 4).

## DISCUSSION

We report here that exercise-induced ST depression was seen in 16.9% of CRD patients without a previous diagnosis

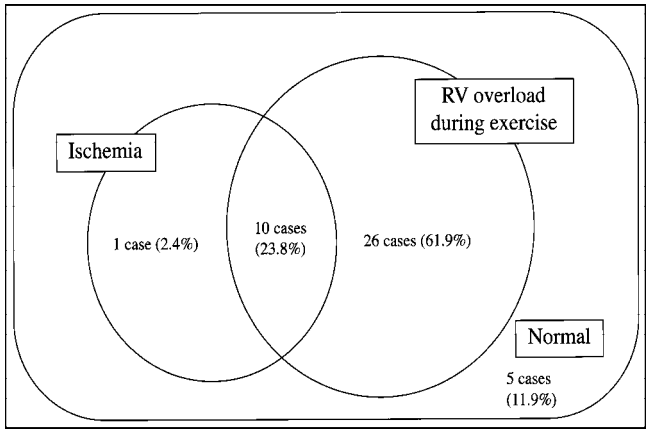


**FIGURE 3.** Relationship between ischemia and RV overload in chronic respiratory disease.

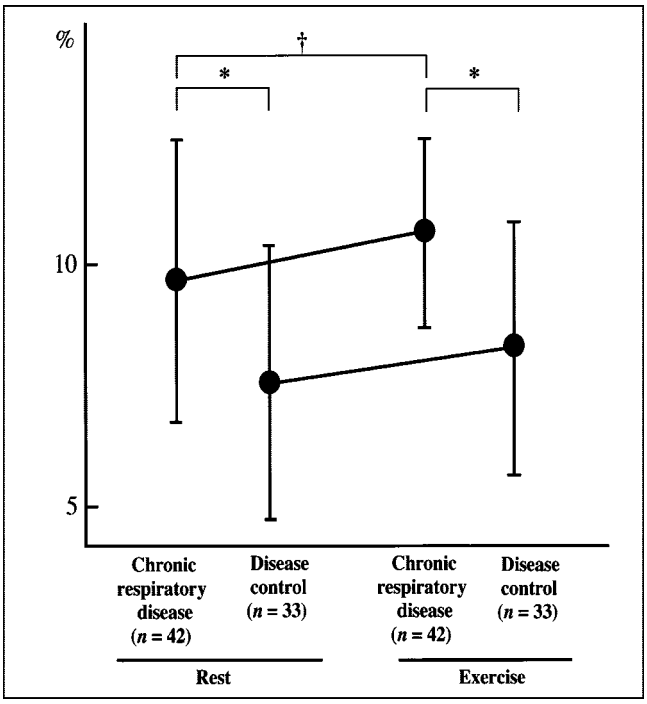


**FIGURE 4.** RV/LV count ratio at rest and during exercise. *$P <$ 0.01 by unpaired *t* test. †$P < 0.05$ by paired *t* test.

of CAD. The population with ST depression, including II, III, and $aV_F$ leads, was unusually large, but this finding did not indicate CAD in all of these patients.

The appearance of ST depression on exercise electrocardiography generally indicates myocardial ischemia. The diagnostic accuracy of exercise electrocardiography in patients with chest symptoms suspected of being caused by CAD is well known. Meta-analysis of 147 consecutively published reports revealed that the mean sensitivity was 68% and the mean specificity was 77% (*10*). However, some factors are known to lower the predictive accuracy of the test. False-positive ST depression during exercise is more likely in the presence of bundle branch block (*7,8*), left ventricular hypertrophy (*11,12*), valvular heart disease (*13*), resting ST depression (*14,15*), and digitalis administration (*16*). In asymptomatic individuals, exercise electrocardiography is also known to have a lower diagnostic value than in symptomatic individuals. In healthy volunteers, the positive predictive value is relatively low, ranging from 24% to 72% (*17–20*). A low predictive value was also reported in asymptomatic patients with noninsulin–dependent diabetes mellitus (*21*), right bundle branch block (*7*), or left bundle branch block (*8*). In this study, although patients with right bundle branch block or left bundle branch block were excluded, all CRD patients with positive ST depression were asymptomatic except for 3: 2 patients felt breathlessness and chest pain and 1 felt only chest pain.

Cardiac perfusion SPECT has resulted in a higher frequency of detection of CAD relative to exercise electrocardiography. The average sensitivity and specificity of qualitative exercise $^{201}$Tl SPECT were reported to be 89% and 76%, respectively (*22*). The average sensitivity and specificity of $^{99m}$Tc perfusion SPECT are thought to be similar to those of $^{201}$Tl SPECT (*22*). Using myocardial perfusion SPECT, we found that the proportion of cardiac ischemia in CRD was lower than that in disease control subjects, indicating that CRD is a condition in which there is false-positive ST depression during exercise.

In our CRD patients with no history of CAD, the prevalence of CAD was 4.4% (11/249). Previous studies have addressed the issue of CAD in CRD patients. Thurnheer et al. (*2*) reported that >70% stenosis of a coronary artery was detected in 20.4% of candidates for volume reduction surgery (9/44), which included 6 patients without a history of CAD. Results of 3 coronary angiographic studies of lung transplantation recipients showed a mean prevalence of coronary stenosis of 9.0% for these 3 studies (37/410) (*23–25*). In a study that included only subjects who had no symptoms of CAD, prevalence was 4.3% (2/46) (*23*), which is similar to our results. It may be more helpful to use pharmacologic agents such as dipyridamole or dobutamine to detect coronary stenosis in CRD patients with limited exercise tolerance (*26*). However, we selected exercise stress testing because we wanted to examine the presence of ischemia under conditions closer to those in daily life.

It is necessary to clarify whether ST depression during exercise truly represents myocardial ischemia in patients with CRD because this information can be used to determine indications and details of medication and respiratory rehabilitation, especially exercise training. Patients found to have CAD should undergo further examination and be administered medication or other interventions before starting respiratory rehabilitation. Furthermore, exercise training should be prescribed not only according to the respiratory condition but also according to cardiac status.

If there is a change in ST depression caused by a disorder other than ischemia, further investigation is necessary to clarify the cause. The existence of cor pulmonale indicates a poor prognosis in CRD (*4*). In undertaking this study, we considered that RV overload might affect the ST segment change during exercise in CRD patients. It has been reported that cardiac perfusion scintigraphy can evaluate RV overload in the chronic phase. Visualization of the RV in planar images is a significant diagnostic finding of pulmonary hypertension and RV hypertrophy (*27–30*). Kawai et al. (*30*) reported that the thallium uptake ratio of the left-to-right ventricle in planar images highly correlates with the left-to-right ventricular mass ratio measured in autopsied patients and that it inversely correlates with mean pulmonary artery pressure in patients with cor pulmonale. Nishijima et al. (*31*) also suggested such a correlation by $^{99m}$Tc-methoxyisobutylisonitrile SPECT. The meaning of an increase in RV uptake during exercise is of importance. Hemodynamic changes during exercise in CRD patients have been studied. Mahler et al. (*32*) reported that COPD patients had an inordinate rise in mean pulmonary artery

pressure plotted against the cardiac index during exercise and that pulmonary vascular resistance rose rather than fell normally with exercise. These rises are caused by both hypoxemic vasoconstriction and pulmonary vascular destruction (*33*,*34*). This pressure overload leads to an adaptive rise in preload and a dilatation of the RV to sustain cardiac output. Wackers et al. (*35*) undertook an experimental study of perfusion scintigraphy of acute RV overload. An acute increase in RV workload by either pressure or volume loading resulted in a substantial increase in RV myocardial blood flow. This acute increase in blood flow thus allowed visualization of the RV in myocardial images. Williams and Schneider (*36*) suggested that an increase of RV uptake in their patients with severe CAD might be due to an elevated pulmonary artery pressure during exercise. Our data showing an increased RV/LV ratio with exercise in CRD patients were compatible with these earlier results. Therefore, exercise cardiac perfusion scintigraphy is a useful technique to evaluate cardiac ischemia and RV overload simultaneously.

Our initial interest was to determine whether exercise-induced ST depression, especially including II, III, aV$_F$ leads, indicates coronary stenosis in CRD patients, but we found that RV overload was a more common phenomenon than ischemia. One limitation of this study is the lack of a demonstration of causality between RV visualization and ST depression. This is not a case-control study from the aspect of evaluating RV overload during exercise. We did not confirm a lack of RV overload in patients without ST depression in CPET. Further examinations of the relationship between exercise-induced RV overload and ST depression, such as exercise testing under pulmonary artery pressure monitoring, are needed.

## CONCLUSION

Exercise-induced ST depression in CRD patients, especially including II, III, and aV$_F$ leads, indicates a small possibility of cardiac ischemia. However, many of these patients have RV overload. Myocardial perfusion SPECT is a useful tool to evaluate the pathophysiology of ST depression in these patients. Before respiratory rehabilitation, especially exercise training, CPET with 12-lead ECG monitoring is necessary in CRD patients. Further examination by myocardial scintigraphy should be performed to detect CAD or RV overload with exercise if positive ST depression is observed.

## REFERENCES


1. Wasserman K, Hansen JE, Sue DY, Casaburi R, Whipp BJ. *Principles of Exercise Testing and Interpretation*. 3rd ed. Baltimore, MD: Lipppincott Williams & Wilkins; 1999:1–9.
2. Thurnheer R, Muntwyler J, Stammberger U, et al. Coronary artery diseases in patients undergoing lung volume reduction surgery for emphysema. *Chest*. 1997; 112:122–128.
3. Ries AL, Carlin BW, Carreri-Kohlman V, et al. Pulmonary rehabilitation: joint ACCP/AACVPR evidence-based guidelines. *Chest*. 1997;112:1363–1396.
4. Weitzenblum E, Hirth C, Ducolone A, et al. Prognostic value of pulmonary pressure in chronic obstructive pulmonary disease. *Thorax*. 1981;36:752–758.
5. Gibbons RJ, Balady GJ, Beasley JW, et al. ACC/AHA guidelines for exercise testing: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Exercise Testing). *J Am Coll Cardiol*. 1997;30:260–315.
6. Chaitman BR. Exercise stress testing. In: Braunwald E, ed. *Heart Disease*. 5th ed. Philadelphia, PA: W.B. Saunders; 1996:157.
7. Whinnery JE, Froelicher VF Jr, Longo MR Jr, et al. The electrocardiographic response to maximal treadmill exercise in asymptomatic men with right bundle branch block. *Chest*. 1977;71:335–407.
8. Whinnery JE, Froelicher VF Jr, Stuart AJ. The electrocardiographic response to maximal treadmill exercise in asymptomatic men with left bundle branch block. *Am Heart J*. 1977;94:316–327.
9. Committee on Advanced Cardiac Imaging and Technology, Council on Clinical Cardiology, American Heart Association, Cardiovascular Imaging Committee, American College of Cardiology and Board of Directors, Cardiovascular Council, Society of Nuclear Medicine. Standardization of cardiac tomographic imaging. *Circulation*. 1992;86:338–339.
10. Gianrossi R, Detrano R, Mulvihill D, et al.. Exercise-induced ST depression in the diagnosis of coronary artery disease: a meta-analysis. *Circulation*. 1989;80: 87–98.
11. Wong HO, Kasser IS, Bruce RA. Impaired maximal exercise performance with hypertensive cardiovascular disease. *Circulation*. 1969;39:633–636.
12. Harris CN. Treadmill stress test in left ventricular hypertrophy. *Chest*. 1973;63: 353–357.
13. Fletcher GF, Balady G, Froelicher VF, et al. Exercise standards: a statement for healthcare professionals from the American Heart Association. *Circulation*. 1995;91:580–615.
14. Surawicz B, Saito S. Exercise testing for detection of myocardial ischemia in patients with abnormal electrocardiograms at rest. *Am J Cardiol*. 1978;41:943–951.
15. Mayers DG, Bendon KA, Hankins JH, et al. The effect of baseline electrocardiographic abnormalities on the diagnostic accuracy of exercise-induced ST segment changes. *Am Heart J*. 1990;119:272–276.
16. Kawai C, Hultgren HN. The effects of digitalis upon the exercise electrocardiogram. *Am Heart J*. 1964;68:409–412.
17. Fleg JL, Gersteinblith G, Zonderman AB, et al. Prevalence and prognostic significance of exercise-induced silent myocardial ischemia detected by thallium scintigraphy and electrocardiography in asymptomatic volunteers. *Circulation*. 1990;81:428–436.
18. Katzel LI, Fleg JL, Busby-Whitehead MJ, et al. Exercise-induced silent myocardial ischemia in master athletes. *Am J Cardiol*. 1998;81:261–265.
19. Hammond HK, Froelicher VF. Normal and abnormal heart rate responses to exercise. *Prog Cardiovasc Dis*. 1985;27:271–279.
20. Erikssen J, Enge I, Forfang K, et al. False positive diagnostic tests and coronary angiographic findings in 105 presumably healthy males. *Circulation*. 1976;54: 371–376.
21. Milan Study on Atherosclerosis and Diabetes Group. Prevalence of unrecognized silent myocardial ischemia and its association with atherosclerotic risk factors in noninsulin-dependent diabetes mellitus. *Am J Cardiol*. 1997;79:134–139.
22. Ritchie JL, Bateman TM, Bonow RO, et al. Guidelines for clinical use of cardiac radionuclide imaging: a report of the AHA/ACC Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures, Committee on Radionuclide Imaging, developed in collaboration with the American Society of Nuclear Cardiology. *Circulation*. 1995;91:1278–1303.
23. Vizza CD, Lynch JP, Ochoa LL, et al. Right and left ventricular dysfunction in patients with severe pulmonary disease. *Chest*. 1998;113:576–583.
24. Thaik CM, Semigran MJ, Ginns L, et al. Evaluation of ischemic heart disease in potential lung transplant recipients. *J Heart Lung Transplant*. 1995;14:257–266.
25. Leibowitz DW, Caputo AL, Shapio GC, et al. Coronary angiography in smokers undergoing evaluation for lung transplantation: Is routine use justified? *J Heart Lung Transplant*. 1994;13:701–703.
26. Shaffer S, Simbartl L, Render ML, et al. Patients with stable chronic obstructive pulmonary disease can safely undergo intravenous dipyridamole thallium-201 imaging. *Am Heart J*. 1998;136:307–313.
27. Cohen HA, Baird MG, Rouleau JR, et al. Thallium 201 myocardial imaging in patients with pulmonary hypertension. *Circulation*. 1976;54:790–795.
28. Newth CJL, Corey ML, Fowler RS, et al. Thallium myocardial perfusion scans for the assessment of right ventricular hypertrophy in patients with cystic fibrosis. *Am Rev Respir Dis*. 1981;124:463–468.
29. Khaja F, Alam M, Goldstein S, et al. Diagnostic value of visualization of the right ventricle using thallium-201 myocardial imaging. *Circulation*. 1979;59:182–188.
30. Kawai S, Tanaka N, Sawada M, et al. The usefulness of thallium-201 myocardial perfusion scintigraphy in the diagnosis of chronic cor pulmonale. *Jpn Circ J*. 1981;45:1003–1013.
31. Nishijima K, Miyahara Y, Furukawa K, et al. Simultaneous assessment of right

ventricular function and hypertrophy by Tc-99m MIBI. *Clin Nucl Med*. 1999;24: 151–155.
32. Mahler DA, Brent BN, Loke J, et al. Right ventricular performance and central circulatory hemodynamics during upright exercise in patients with chronic obstructive pulmonary disease. *Am Rev Respir Dis*. 1984;130:722–729.
33. Matthay RA, Niederman MS, Wiedemann HP. Cardiovascular pulmonary interaction in chronic obstructive pulmonary disease with special reference to the pathogenesis and management of cor pulmonale. *Med Clin North Am*. 1990;74:571–617.
34. Schulman DS, Matthay RA. The right ventricle in pulmonary disease. *Clin Cardiol*. 1992;10:111–135.
35. Wackers FJ, Kley JW, Laks H, et al. Pathophysiologic correlates of right ventricular thallium-201 uptake in a canine model. *Circulation*. 1981;64:1256–1264.
36. Williams KA, Schneider CM. Increased stress right ventricular activity on dual isotope perfusion SPECT: a sign of multivessel and/or left main coronary artery disease. *J Am Coll Cardiol*. 1999;34:420–427.

## Erratum

In "Cellular Dose Conversion Factors for α-Particle–Emitting Radionuclides of Interest in Radionuclide Therapy," by Hamacher et al. (*J Nucl Med.* 2001;42:1216–1221), portions of Table 1 and Figure 2 were incorrect. The correct table and figure appear below. The authors regret the error.

**TABLE 1**
Cellular S Values for $^{213}$Po

| $R_C$ (μm) | $R_N$ (μm) | S(C ← C) (Gy/Bq/s) | S(C ← CS) (Gy/Bq/s) | S(N ← N) (Gy/Bq/s) | S(N ← Cy) (Gy/Bq/s) | S(N ← CS) (Gy/Bq/s) |
|---|---|---|---|---|---|---|
| 3 | 2 | 1.95E−01 | 1.30E−01 | 4.37E−01 | 1.50E−01 | 9.74E−02 |
| 3 | 1 | 1.95E−01 | 1.30E−01 | 1.74E+00 | 1.97E−01 | 8.97E−02 |
| 4 | 3 | 1.10E−01 | 7.36E−02 | 1.95E−01 | 8.02E−02 | 5.70E−02 |
| 4 | 2 | 1.10E−01 | 7.36E−02 | 4.37E−01 | 9.66E−02 | 5.23E−02 |
| 5 | 4 | 7.05E−02 | 4.72E−02 | 1.10E−01 | 4.99E−02 | 3.76E−02 |
| 5 | 3 | 7.05E−02 | 4.72E−02 | 1.95E−01 | 5.73E−02 | 3.45E−02 |
| 5 | 2 | 7.05E−02 | 4.72E−02 | 4.37E−01 | 6.75E−02 | 3.29E−02 |
| 6 | 5 | 4.91E−02 | 3.29E−02 | 7.05E−02 | 3.41E−02 | 2.67E−02 |
| 6 | 4 | 4.91E−02 | 3.29E−02 | 1.10E−01 | 3.80E−02 | 2.46E−02 |
| 6 | 3 | 4.91E−02 | 3.29E−02 | 1.95E−01 | 4.32E−02 | 2.34E−02 |
| 7 | 6 | 3.62E−02 | 2.42E−02 | 4.91E−02 | 2.48E−02 | 2.01E−02 |
| 7 | 5 | 3.62E−02 | 2.42E−02 | 7.05E−02 | 2.71E−02 | 1.85E−02 |
| 7 | 4 | 3.62E−02 | 2.42E−02 | 1.10E−01 | 3.01E−02 | 1.76E−02 |
| 7 | 3 | 3.62E−02 | 2.42E−02 | 1.95E−01 | 3.38E−02 | 1.70E−02 |
| 8 | 7 | 2.77E−02 | 1.86E−02 | 3.62E−02 | 1.89E−02 | 1.56E−02 |
| 8 | 6 | 2.77E−02 | 1.86E−02 | 4.91E−02 | 2.03E−02 | 1.45E−02 |
| 8 | 5 | 2.77E−02 | 1.86E−02 | 7.05E−02 | 2.22E−02 | 1.38E−02 |
| 8 | 4 | 2.77E−02 | 1.86E−02 | 1.10E−01 | 2.45E−02 | 1.33E−02 |
| 9 | 8 | 2.20E−02 | 1.48E−02 | 2.77E−02 | 1.49E−02 | 1.25E−02 |
| 9 | 7 | 2.20E−02 | 1.48E−02 | 3.62E−02 | 1.58E−02 | 1.16E−02 |
| 9 | 6 | 2.20E−02 | 1.48E−02 | 4.91E−02 | 1.71E−02 | 1.11E−02 |
| 9 | 5 | 2.20E−02 | 1.48E−02 | 7.05E−02 | 1.86E−02 | 1.07E−02 |
| 10 | 9 | 1.79E−02 | 1.21E−02 | 2.20E−02 | 1.21E−02 | 1.03E−02 |
| 10 | 8 | 1.79E−02 | 1.21E−02 | 2.77E−02 | 1.27E−02 | 9.59E−03 |
| 10 | 7 | 1.79E−02 | 1.21E−02 | 3.62E−02 | 1.35E−02 | 9.15E−03 |
| 10 | 6 | 1.79E−02 | 1.21E−02 | 4.91E−02 | 1.46E−02 | 8.82E−03 |
| 10 | 5 | 1.79E−02 | 1.21E−02 | 7.05E−02 | 1.57E−02 | 8.59E−03 |

$R_C$ = cellular radius; $R_N$ = nuclear radius; C = cell volume; CS = cell surface; N = nucleus; Cy = cytoplasm; S(X ← Y) = S factor for X target and Y source.

*(continued on page 436)*