Motion Correction in Exercise First-Pass Radionuclide Ventriculography without an External Point Source

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Exercise first-pass radionuclide ventriculography provides valuable diagnostic and prognostic information in patients with coronary artery disease. In this procedure, motion correction of the images is commonly performed using a second external point source attached to the chest wall during exercise (dual-isotope method). Recently, a motion correction algorithm without an external point source (single-isotope method) was developed and the results compared with those of the dual-isotope method. **Methods:** To examine the accuracy of the motion correction method, a phantom study was performed using a moving cardiac phantom with a motion speed of up to 169 cycle/min and motion amplitude up to 6 cm. Count fluctuation in the phantom region by motion was calculated as a coefficient of variation (CV). In the clinical study, time-activity curves of the left ventricular phase were created for quantitative assessment of variation as CV values of the ejection fraction in the central five cardiac cycles after correction by the two methods during exercise radionuclide ventriculography in 17 patients. **Results:** In the moving phantom, both the single- and dual-isotope methods reduced the CV values less than 10%. In the clinical study, the single-isotope method provided less CV value of ejection fraction (9.8% ± 5.6%) than the dual-isotope method (24.8% ± 10.5%) ($p < 0.01$), indicating less individual variation of ejection fraction values. **Conclusion:** These data indicate that object motion can be accurately corrected in the moving phantom by both single- and dual-isotope methods. In clinical studies, the single-isotope method is more accurate.

Key Words: radionuclide ventriculography; exercise stress testing; technetium-99m-tetrofosmin; coronary artery disease

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Newly developed ^{99m}Tc perfusion agents permit simultaneous assessment of left ventricular (LV) perfusion and function (*1–6*). Particularly, the exercise ventricular function study is available with first-pass radionuclide ventriculography using a multicrystal gamma camera (*2,3,5,6*). An external point source, however, has to be prepared in each study for motion correction during acquisition (dual-isotope method) (*7–9*). To simplify the test, a new method for motion correction without an external point source has been tested (single-isotope method). The purpose of this study was to assess the feasibility of the single-isotope method for motion correction during the first-pass radionuclide ventriculography and compare the accuracy of motion correction with the more commonly performed dual-isotope method using a moving phantom and patient data during treadmill exercise.

METHODS

Radionuclide Ventriculography

Dynamic images were acquired every 25 msec in the anterior projection using a multicrystal gamma camera equipped with a high-sensitivity collimator.

A cone-shaped plastic cardiac phantom filled with 133 ml ^{99m}Tc solution (0.7 MBq/ml) (19 μCi/ml) was used in the phantom study. The phantom was placed on a moving plate in front of the gamma camera 5 cm from the collimator surface in a room air. Approximately 37–74 MBq (1–2 mCi) ^{125}I as an external point source was placed on the anterior surface of the phantom for motion correction with the dual-isotope method. Initially, the phantom was placed on the moving plate with the motion amplitude set from 0 to 6 cm with a speed of 120 cycle/min. Then, the phantom was moved in one direction with the motion speed from 0, 50, 95, 120, 145 and 169 cycle/min with an amplitude of 3 cm. After determining regions of interest (ROIs) in the phantom image, a time-activity curve was created. To evaluate count fluctuation by motion, the coefficient of variation (CV) of the count in the phantom image was calculated.

First-pass radionuclide ventriculography was performed during treadmill exercise in 17 subjects, including 11 patients with coronary artery disease (CAD) and 6 normal volunteers. Approximately 74 MBq (2 mCi) ^{125}I as an external point source was placed in the anterior chest wall of the subject. All subjects performed treadmill exercise with Stage II (n = 3), III (n = 7) or IV (n = 7) Bruce protocol at peak exercise. At peak exercise, 740 MBq (20 mCi) ^{99m}Tc-tetrofosmin were administered as a bolus into the antecubital vein, and radionuclide ventriculography was performed during exercise every 25 msec per frame. After motion correction, the time-activity curves of the LV phase with a single end-diastolic ROI were used to calculate beat-to-beat ejection

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FIGURE 1. Left ventricular image with a large ROI placed over the left ventricle and ascending aorta to determine the centroid of the image for motion correction (single-isotope method).

fraction in five central cardiac cycles. For quantitative assessment of variation of ejection fraction values due to the motion, the CV values were calculated to compare the results between the two methods.

Motion Correction Methods

In the single-isotope method without an external point source, the uncorrected LV motion images were displayed for placement of a large ROI over the left ventricle and ascending aorta (Fig. 1). A time-activity curve for the ROI was then generated. The representative portion of the LV phase was selected by denoting a beginning and ending cardiac cycle. The centroid of this ROI was determined in each frame (Fig. 1). The spatial location of the image data frame was repositioned by moving the centroid location for the composite image data frame the over the LV phase (*10*).

In the dual-isotope method, the ^{125}I point source fixed on the anterior chest wall was used as a reference position. Dual photopeak (140 keV for ^{99m}Tc and 30 keV for ^{125}I) was obtained during data acquisition. The principal photopeaks of the two isotopes were separated. After drawing ROIs of the LV region and the point source, the centroids of the images were determined on the computer. The ^{125}I point source was detected by the camera. The spatial location of the image data frame was repositioned by moving the centroid location of the external point source over the LV phase.

In both motion correction methods, patient motion correction was also applied to correct for beat-to-beat variation of the images during the LV phase. The end-diastolic image of the selected representative cardiac cycle was displayed. After noise and background correction, a composite mask was created by combining the end-diastolic and end-systolic masks. To amend position changes due to cardiac contraction, the composite mask was applied to the representative image data frames made up of the characteristic time segments of the summed cardiac cycles.

Statistical Analysis

Data were expressed as mean ± 1 s.d. The difference in the mean CV values was assessed by Student's t-test for paired data. Probability values less than 0.05 were considered significant.

RESULTS

Phantom Study

Figure 2 shows the time-activity curves of the phantom before and after motion correction with a motion amplitude of 5 and 1 cm. The count fluctuation observed without motion correction was reduced after motion correction by both techniques.

Count fluctuation by motion was displayed as a CV value before and after motion correction as a function of motion

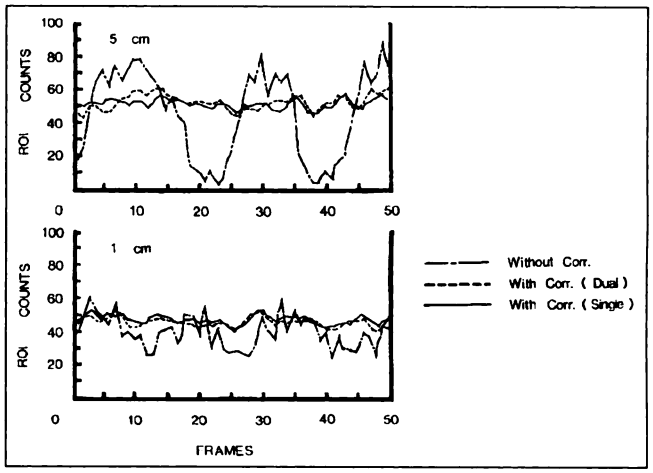

FIGURE 2. Time-activity curves of the phantom before and after motion correction with a motion amplitude of 5 cm (top) and 1 cm (bottom).

amplitude at a speed of 120 cycle/min (Fig. 3). Although the CV values increased up to 60% with a motion amplitude of 4–6 cm, this value was reduced below 10% after motion correction by either technique with the motion length up to 6 cm.

Count fluctuation by motion was displayed before and after motion correction as a function of motion speed at an amplitude of 3 cm (Fig. 4). Although the CV values increased above 30% without motion correction, these values were reduced below 10% after motion correction by either technique with a motion speed up to 170 cycle/min.

Clinical Study

Figure 5 shows end-diastolic and end-systolic LV images during exercise before and after motion correction by the single- and dual-isotope methods. The up and down motion was accurately corrected by the single-isotope method but not by the dual-isotope method. Figure 6 shows typical time-activity curves of the LV phase using a single end-

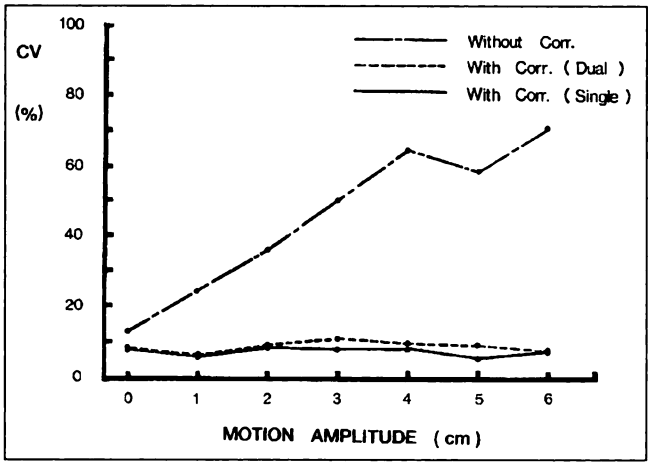

FIGURE 3. Count fluctuation by motion was displayed as a CV value before and after motion correction as a function of motion amplitude at a speed of 120 cycle/min.

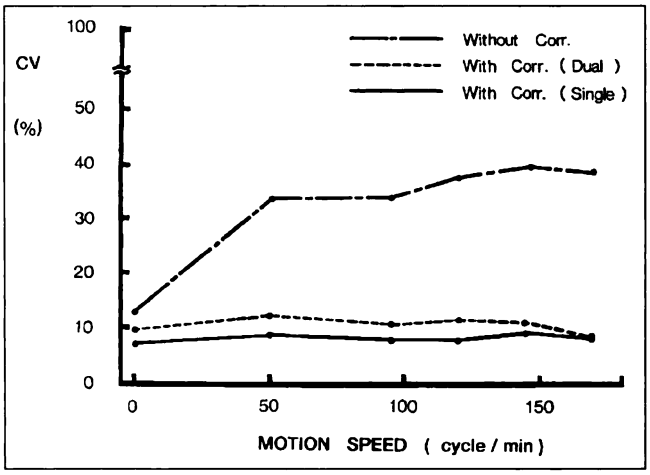

FIGURE 4. Count fluctuation by motion was displayed before and after motion correction as a function of speed at a length of 3 cm.

diastolic ROI after motion correction by the single- and dual-isotope methods. Although LVEF values fluctuated with the dual-isotope method, the single-isotope method provided more stable time-activity curves with smaller fluctuation of the ejection fraction values. The CV values of ejection fraction in the central five cardiac cycles were significantly smaller with the single-isotope method (9.8% ± 5.6%) than those of the dual-isotope method (24.8% ± 20.5%) ($p < 0.01$) and tended to be smaller than those of noncorrected data (13.9% ± 8.7%) ($p = 0.05$), indicating less fluctuation of ejection fraction value with the single-isotope method.

DISCUSSION

These data indicate that object motion can be accurately corrected in a moving phantom by both single- and dual-isotope methods. In the clinical study, however, the single-isotope method was more accurate for motion correction and provided better quality LV images than the dual-isotope method.

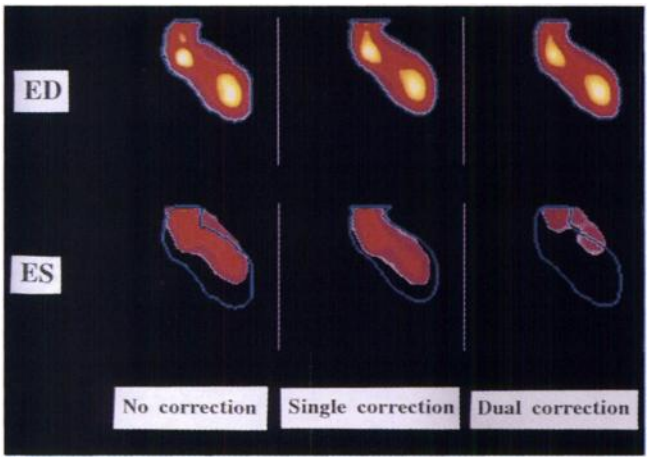

FIGURE 5. End-diastolic (top) and end-systolic images (bottom) during exercise without motion correction (left) and after motion correction using the single-isotope method (middle) and dual-isotope method (right). Up and down LV motion was accurately corrected by the single-isotope method but not by the dual-isotope method.

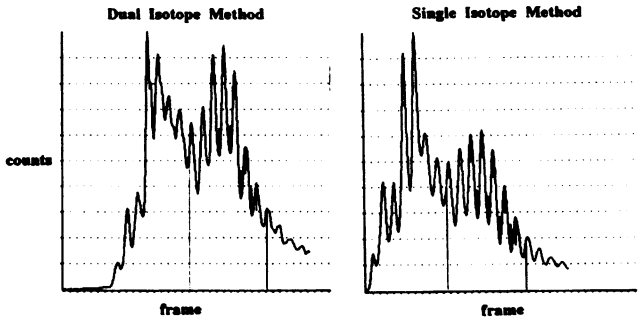

FIGURE 6. The time-activity curves of the left ventricular phase using a single end-diastolic ROI after motion correction by the dual- (left) and single-isotope (right) methods. There is less fluctuation of the left ventricular time-activity curve in the single-isotope method.

Radionuclide ventriculography has long been used to assess ventricular function in the clinical setting with either first-pass angiography of the equilibrium multigated blood-pool imaging. Availability of a single-crystal gamma camera creates better LV images and permits wider application of equilibrium gated blood-pool imaging than first-pass ventriculography. Recently, the introduction of ^{99m}Tc perfusion agents such as ^{99m}Tc-sestamibi and ^{99m}Tc-tetrofosmin have permitted tracer administration of a larger dose to enable first-pass ventriculography during tracer administration before acquiring perfusion images (*1–6*). Thus, combined assessment of LV function and perfusion is feasible and provides valuable diagnostic and prognostic information in the study of patients with CAD (*11–17*).

With first-pass ventriculography, ventricular function can be evaluated during tracer administration. Since exercise perfusion scans are most commonly obtained for evaluating patients with CAD, exercise ventricular function with first-pass ventriculography can provide more information for the diagnosis and severity of CAD. The treadmill is commonly used for exercise electrocardiography and myocardial perfusion imaging. Treadmill exercise, however, may not be routinely applied to stress radionuclide ventriculography because of excessive patient motion. To correct for patient motion during treadmill exercise, an external radionuclide point source is often placed on the chest wall as a marker of ventricular position (*7–9*). This motion correction, however, may not be as accurate when analyzing prolonged physical exercise.

The algorithm used here was based on motion correction of the centroid of its own image. This technique has been used to correct respiratory motion during hepatic scintigraphy (*18–20*). The centroid of the image can be easily determined by a digital computer. To determine the optimum position of the heart in the exercise first-pass study, a large ROI should be placed over the LV and ascending aorta. A smaller ROI only within the LV might possibly cause artifacts due to LV contraction.

This phantom study indicated that such motion correc-

tion can be accurately performed by either the single- or dual-isotope method. The CV value of the image counts were reduced when the motion amplitude was up to 6 cm and motion speed was up to 169 cycle/min with sequential data acquisition 25 msec per frame. During treadmill exercise, respiratory motion ranged from 30 to 50 breaths per min, and the walking motion ranged from 60 to 100 steps per min. The vertical motion of the external point source ranged from 4 to 6 cm. Therefore, amplitude and speed ranges in our phantom study can cover most of the body motion during treadmill exercise.

On the other hand, our clinical studies demonstrated the superiority of the single-isotope method to correct motion in treadmill exercise radionuclide ventriculography for a number of reasons. First, each patient should hyperventilate during vigorous exercise. Therefore, body and the respiratory motion should be considered for motion correction during exercise first-pass ventriculography. The former can be corrected by either the dual- or single-isotope method, but the latter may not accurately correct the motion of the external point source. In this respect, motion correction using its own image (single-isotope method) appears to be more suitable. Second, although each patient was asked to walk away from the collimator surface, the patient's chest was sometimes pushed against the collimator surface during vigorous treadmill exercise. In this case, the external point source may be jammed against the collimator and may not accurately track the motion of the patient's chest. Third, the external point source might be out of the camera's field of view during treadmill exercise. These factors could explain why the dual-isotope method provided tremendous error with large fluctuations in ejection fraction value (Fig. 5). Furthermore, the single-isotope method does not require preparation of an external point source or its attachment on the chest wall and, thus, it may reduce preparation time substantially. The calculation time was approximately the same as that of the dual-isotope method.

Although we used treadmill exercise in this study, bicycle exercise may reduce body motion during first-pass ventriculography. Treadmill exercise, however, can obtain greater exercise levels (*9*), which are better for stress perfusion studies.

Americium-241 is commonly used as an external point source for motion correction, but it has not been approved for use in our institution. Therefore, we cannot definitively assert the superiority of the single-isotope method over the dual-isotope method. The camera we used, however, can trace activity as low as 30 keV. In addition, our phantom study demonstrated that the moving phantom can be accurately traced by the ^{125}I external point source.

CONCLUSION

A newly developed method for motion correction by amending the position of the centroid of the image is feasible during exercise first-pass radionuclide ventriculography. This technique appears to be more accurate for clinical studies than the commonly used dual-isotope method using an external point source.

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