Validation of a Reliable, Noninvasive Method for Determining Right Ventricular Ejection Fraction

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Paired scintigraphic and cine CT studies were performed on 29 patients to assess the accuracy of three scintigraphic methods currently available for determination of right ventricular ejection fraction (RVEF). Following a bolus injection of 30 mCi [^{99m}Tc]pertechnetate, a serial mode acquisition of the first transit through the heart was recorded. Processing was performed in three ways: beat-by-beat (fixed ROI), equilibrium multigated acquisition (MUGA) (variable ROI), and first-pass MUGA (variable ROI). RVEF values determined with the first-pass MUGA technique showed the best correlation with cine CT values, while those determined with the beat-by-beat or the equilibrium MUGA techniques consistently underestimated the RVEF. Thus, the scintigraphic technique using a first-pass gated format with variable ROI appears to be reliable by correlation with cine CT as an inexpensive, noninvasive method for evaluation of RV function.

The assessment of right ventricular ejection fraction (RVEF) plays a key role in the clinical management of right ventricular dysfunction due to infarct, valvular disease, pulmonary dysfunction, or congestive heart failure (*1–6*). This measurement cannot be obtained reliably from cardiac catheterization studies, as the irregular geometry of the right ventricle precludes an adequate approximation of the chamber volume from one or even two projections (*1,2,4,5,7*). Furthermore, this approach is both invasive and costly and cannot be applied in routine clinical practice (*8*). Development of a reliable method to measure RVEF by scintigraphic technique, therefore, is of great importance in the rapidly evolving field of nuclear cardiology.

Historically, the validation of nuclear medicine approaches in assessing RVEF has been hampered by lack of an appropriate gold standard. Recently, however, an independent and reliable method has become available with the development of cine computed tomography (cine CT) (*9*). This technique utilizes an ultrafast CT machine to obtain transverse images of the heart with a temporal resolution of 10 frames per cardiac cycle. The chambers are visualized by prior injection of a nonionic IV contrast medium. Cine CT ejection fraction measurements have been validated using volumetric and flow measurement studies in animals (*9*). Radiopaque right ventricle casts of varying sizes were imaged with cine CT and the volume measurements were compared with those obtained from water displacement when the casts were immersed in water (Fig. 1A). In a second set of experiments, the RV stroke volume was measured both by cine CT and electromagnetic flow meters placed over pulmonary artery. There was an excellent agreement between the two methods (Fig. 1B) with a correlation of r = 0.99 (*9*). However, cine CT is not always practical or available in many hospitals. In most hospitals, noninvasive scintigraphic methods are routinely used for RVEF determination. Therefore, the purpose of this study was to develop a scintigraphic method that would best correlate with the independent RVEF values determined by planimetric cine CT method.

MATERIALS AND METHODS

Scintigraphic studies were performed in 29 patients whose RVEF by cine CT varied from 16% to 87%. These patients were studied with a small field of view scintillation camera* using a collar shield that limited the field of view to ~17 cm and reduced the count rate by ~35% (*10*). Data were acquired in serial mode during the first transit of the tracer through the heart. The camera was positioned with a 15° right anterior oblique (RAO) angulation in order to best visualize the tricuspid valve plane. Twenty minutes after the patient was injected with 5.1 mg stannous pyrophosphate†, an intravenous line was established in the right medial basilic vein using an infusion set with a 22-gauge needle. Thirty millicuries of [^{99m}Tc]pertechnetate in a volume of 2 ml was then rapidly injected followed by a bolus flush of 10–15 ml of normal saline. We have determined that this technique provides a satisfactory first-pass curve in the majority of patients.

Scintigraphic data were then analyzed using three different methods to calculate the RVEF. The first approach, or con-

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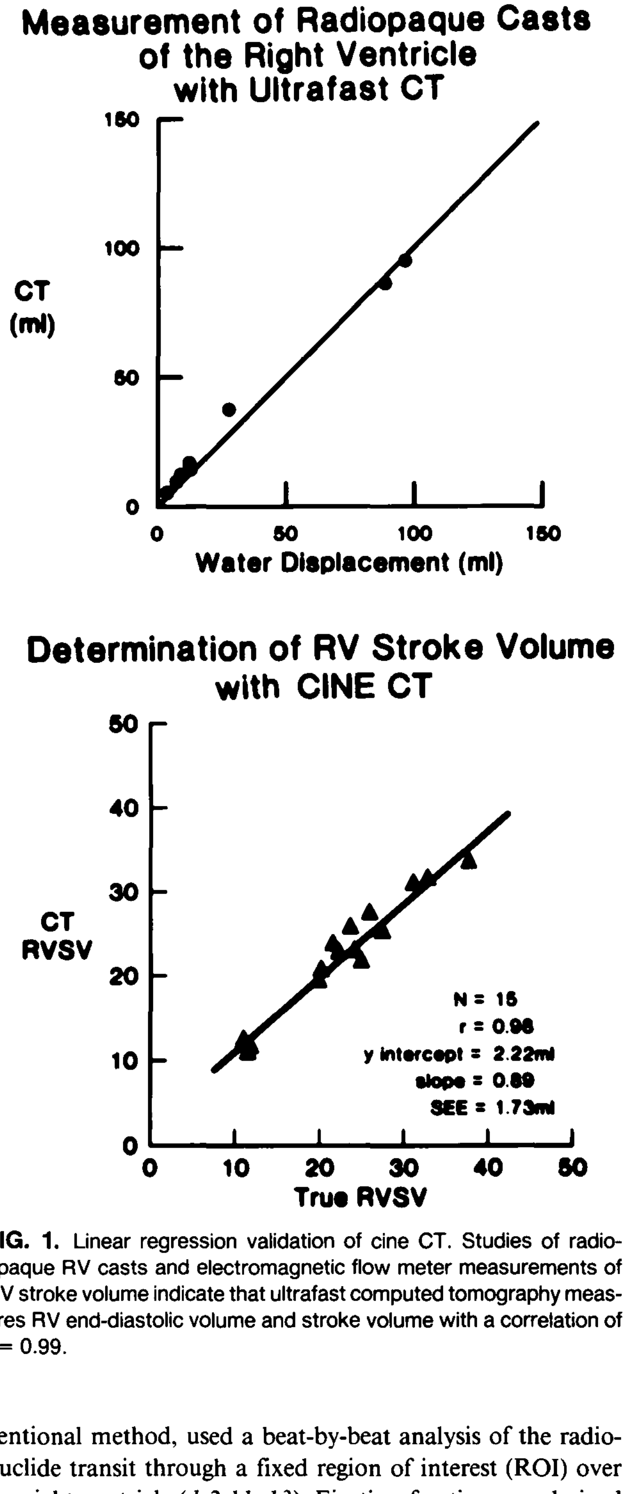

FIG. 1. Linear regression validation of cine CT. Studies of radio-opaque RV casts and electromagnetic flow meter measurements of RV stroke volume indicate that ultrafast computed tomography measures RV end-diastolic volume and stroke volume with a correlation of r = 0.99.

ventional method, used a beat-by-beat analysis of the radionuclide transit through a fixed region of interest (ROI) over the right ventricle (*1,2,11–13*). Ejection fraction was derived from an average of three contiguous beats on the plateau portion of the curve. The second approach, or equilibrium (multigated) MUGA method, used a standard LAO view of a gated equilibrium study and utilized variable ROIs to determine the end-diastolic and end-systolic right ventricle counts (*1,11,13*). The ejection fraction was derived from an average of 200 beats with temporal resolution of 20 frames per cardiac cycle. The third approach, or first-pass MUGA method, used a technique that constructed a composite cycle of a ECG-gated first transit study and utilized variable ROIs to determine the end-diastolic and end-systolic right ventricle counts (Fig. 2) (*14*). The ejection fraction was derived from an average of four beats with a temporal resolution of 16 frames per cardiac cycle.

Cine CT studies were obtained with the patient in a supine position. Fifty cubic centimeters of IV contrast was injected through an arm vein, and transverse images of the heart were obtained at the rate of 17 frames/sec. Each frame consisted of eight contiguous and nonoverlapping slices of the heart that spanned a total of 8 cm. The entire right ventricle was, thus, imaged in two separate runs with the patient's table indexed by 8 cm between the two studies. The temporal resolution was 10 frames per cardiac cycle.

RESULTS

Right ventricular ejection fraction values calculated by each of the scintigraphic methods were compared to the RVEF values by cine CT utilizing linear regression analysis. Results are shown in figure 3, where the Y axis denotes the scintigraphic RVEF determinations and the X axis shows the CT values. With the first-pass curve (beat-by-beat) approach, shown on the left, the slope of the correlation was only 0.37, the intercept was 17%, and the correlation coefficient was r = 0.63. Thus, the conventional first-pass curve technique substantially underestimated RVEF by 15 to 20 percentage points when compared with the values by cine CT. With the equilibrium MUGA method, shown in the middle, the slope of correlation was 0.59, the intercept was 14%, and the correlation coefficient was r = 0.71. In the first-pass MUGA method, however, the slope of the correlation was 0.91, the intercept was 5.9%, and the correlation coefficient was r = 0.96. Both the precision and the accuracy of the RVEF determinations by the first-pass MUGA technique were superior to those obtained by the first-pass curve analysis or the equilibrium MUGA method.

A frame-by-frame review of the right ventricle images disclosed substantial translational motion of the tricuspid valve plane between end-diastole and end-systole (Fig. 4). This shortening of the long axis of the right ventricle ranged from 17% to 55%, with a mean value of 37%. Valve plane motion was noted to be greater with higher RVEF values and, therefore, produced a larger error with the use of a fixed ROI.

DISCUSSION

We believe the underestimation of the RVEF with the conventional method is primarily due to the incomplete sampling of the right ventricle and/or partial inclusion of right atrium brought about by the use of a fixed ROI. As shown in figure 4, there is substantial displacement of the tricuspid valve between end-diastole and end-systole. Since the atrial time-activity is totally out of phase with the right ventricular activity, the inclusion of the atria in the RV region will invariably result in underestimation of RVEF. The magnitude of this error will be proportional to the extent of valve displacement and therefore is likely to be greater for higher ejection fraction measurements.

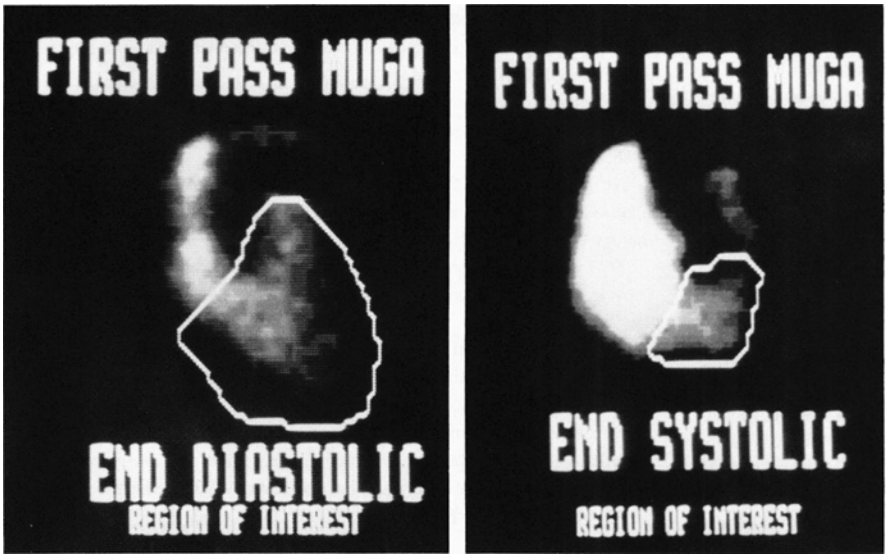

FIG. 2. First-pass analysis with ECG gating to construct a composite cardiac cycle. Individualized ROIs were assigned to the right ventricle at end-diastole and end-systole.

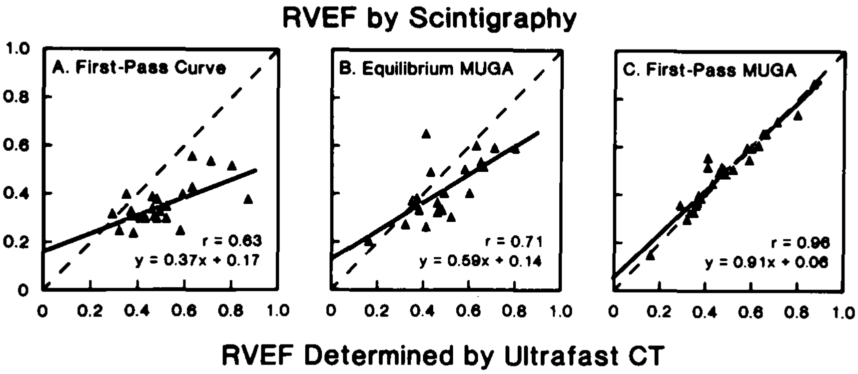

FIG. 3. The RVEF determinations derived with each of the three scintigraphic methods were correlated independently with the CT measurements in each patient utilizing linear regression analysis.

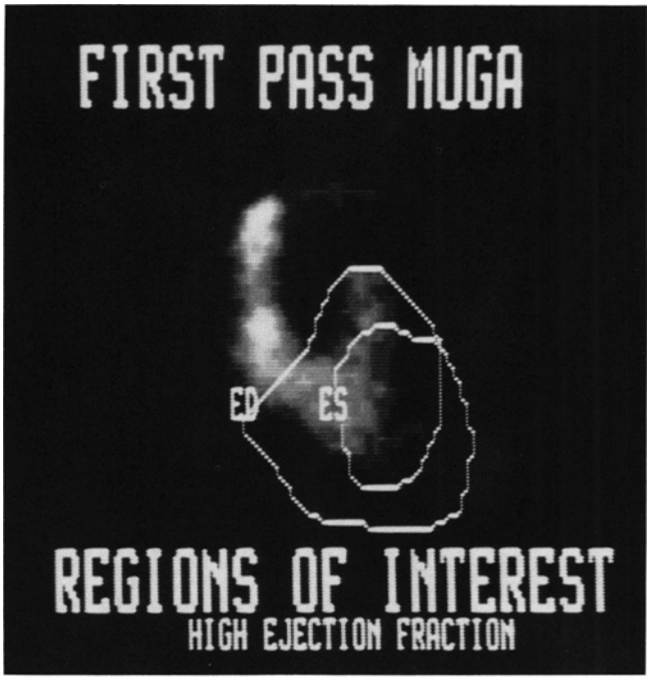

FIG. 4. There was substantial motion of the tricuspid valve plane between end-diastole and end-systole shown on CT and first-pass MUGA studies. Hence, a fixed ROI systematically underestimates RVEF due to partial and variable inclusion of the right atrium in the RV ROI.

The underestimation of the RVEF with the equilibrium MUGA method is thought to be due to inadequate separation of the RV from other blood-pool structures (*15*). Since the first-pass MUGA approach uses a variable ROI and is separated from any overlapping structures, it provides a better correlation with cine CT and produces a more accurate assessment of RVEF.

In conclusion, our data suggest that conventional radionuclide RVEF determinations systematically underestimate the true RVEF by 15%–20%. The first-pass MUGA approach, on the other hand, can provide an accurate and noninvasive determination of RVEF and should be adopted as the scintigraphic method of choice for this purpose.

NOTES

* Siemens, Shamburg, IL.

† Mallinckrodt, Inc., St. Louis, MO.

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