Right and Left Ventricular Volume and Ejection Fraction by Tomographic Gated Blood-Pool Scintigraphy

Bennett B. Chin, Daniel C. Bloomgarden, Weishi Xia, Hee-Joung Kim, Zahi A. Fayad, Victor A. Ferrari, Jesse A. Berlin, Leon Axel and Abass Alavi

Department of Radiology and Radiological Sciences, Johns Hopkins Medical Institutions, Baltimore, Maryland; Departments of Radiology and Nuclear Medicine, Cardiology and Clinical Epidemiology and Biostatistics, Hospital of the University of Pennsylvania, Philadelphia, Pennsylvania

Tomographic techniques separate overlying structures, permitting measurements of absolute ventricular volumes. The purpose of this study was to determine absolute right and left ventricular volume and ejection fraction measurements with tomographic gated equilibrium blood-pool scintigraphy (TMUGA) compared to MRI and conventional planar scintigraphy. **Methods:** Eighteen patients were studied. Ventricular volumes for TMUGA and MRI were calculated by modified Simpson's rule. TMUGA regions were defined by constraints including phase analysis, intensity threshold and visual inspection. MRI studies were acquired with a fast gradient-echo, ECG-gated, breath-hold technique and boundaries were defined by a semiautomated contour method. Conventional gated first-pass radionuclide angiography (FP) and planar gated equilibrium blood-pool scintigraphy (PMUGA) were performed for RV EF and LV EF, respectively. **Results:** TMUGA absolute right ventricular volumes showed excellent correlation with MRI for both right ventricular volumes (r = 0.91, slope = 0.90, s.e.e. = 15.7) and left ventricular volumes (r = 0.96, slope = 0.88, s.e.e. = 18.2). For left ventricular ejection fraction, TMUGA also showed excellent correlation with MRI (r = 0.94, slope = 1.10, s.e.e. = 9.0) and planar MUGA (r = 0.97, slope = 1.23, s.e.e. = 6.2). For right ventricular ejection fraction, TMUGA showed good correlation with both MRI (r = 0.88, slope = 0.79, s.e.e. = 6.0) and first-pass planar scintigraphy (r = 0.86, slope = 1.2, s.e.e. = 7.9). **Conclusion:** Tomographic gated blood-pool scintigraphy absolute right and left ventricular volumes and ejection fractions show good correlation with accepted techniques. Further studies are necessary to define the reproducibility of this method.

Key Words: tomographic equilibrium gated blood-pool scintigraphy; magnetic resonance imaging; cardiac volume

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Accurate quantification of ventricular function may improve effective patient management by providing diagnostic information for cardiac assessment, measurements of the improvement or deterioration of function in response to therapy, and prognostic information defining patients who are at high risk for cardiac death. The most commonly used objective index of left ventricular dysfunction is left ventricular ejection fraction (LV EF). In patients with left-sided heart failure or valvular regurgitation, a detectable decrease in ejection fraction at rest is commonly a late or insensitive indicator of dysfunction (1–4). Similarly, in patients with primary pulmonary hypertension or intrinsic lung disease and right heart failure, a decrease in right ventricular ejection fraction (RV EF) is often a late indicator of

dysfunction (5). Before changes in ejection fraction, increases in ventricular volumes may occur as early compensatory changes before severe dysfunction (5,6). Absolute ventricular volume measurements may also provide the basis for other indices of ventricular function including cardiac output, stroke volume and absolute ventricular filling and emptying rates.

Planar imaging techniques, including gated radionuclide first-pass (FP) and gated equilibrium blood-pool scintigraphy (MUGA), are limited due to the incomplete separation of cardiac structures. Contrast angiography and echocardiography are limited due to the geometric assumptions used in measurements. Right ventricular volume measurements are even less accurate because of the complex geometry that does not conform to simple models. In addition to this complex shape, the right ventricle is also more difficult to separate from overlapping structures.

Tomographic techniques, including MRI and CT, have quantified ventricular volumes with excellent results (7–13). However, these techniques may be technically difficult (e.g., breath-holding in patients with severe lung disease or heart failure, or in claustrophobic patients) and are cost prohibitive. Tomographic gated blood imaging scintigraphy (TMUGA) is a technically simple and widely available method which may provide simultaneous assessment of right and left ventricular volumes and function. This study compares tomographic MUGA right and left ventricular volume and ejection fraction measurements with tomographic (MRI) and conventional planar (radionuclide) techniques.

MATERIALS AND METHODS

Patients

Patients referred for the evaluation of ventricular function were the source of subjects in this study. Studies were collected prospectively in accordance with guidelines set forth by the institutional review board. Eighteen patients (11 men, 7 women) with a mean age of 46.5 ± 16.5 yr (range 25–77 yr) were included. Referrals included patients evaluated for known or suspected coronary artery disease (n = 4), congestive heart failure (n = 1), lung transplantation (n = 4), pulmonary hypertension (n = 3), chemotherapy (n = 5) or heart transplantation (n = 1).

With the exception of two patients, all MRI studies were performed on the same day as TMUGA. All radionuclide FP studies were followed immediately by TMUGA on the same day. Inclusion criteria for MRI studies included all patients willing and able to complete both MRI and TMUGA within 2 wk. Inclusion criteria for FP studies included all patients with adequate data acquisition of FP who were willing and able to complete both FP and TMUGA. In addition, several patients willing to have FP

studies in addition to TMUGA did not have FP due to inadequate antecubital venous access or poor bolus. Several patients were unwilling or unable to undergo MRI due to claustrophobia. Most patients were unable to complete all the studies due to conflicting physician appointments and scanner scheduling times. Only two patients had MRI, FP and TMUGA. Exclusion criteria included all studies with poor quality MRI or FP due to inadequate or insufficient data acquisition. All patients had adequate PMUGA and TMUGA studies. Ten patients had both MRI and TMUGA. Ten patients had FP and TMUGA.

Radionuclide Phantom Studies

Previous studies have shown good results quantifying LV volumes in patients using thresholds based on phantom studies (14–16). Volumes measured by the thresholding technique include all voxels above a percent of the maximum count. Factors affecting volume quantitation based on this method include system spatial resolution, reconstruction parameters, object size and shape, voxel size, surrounding activity, scatter, attenuation and noise (17,18). To compensate for these factors with our specific imaging system and acquisition technique, cardiac phantom studies were performed to determine an appropriate threshold.

A cardiac phantom (Dataspectrum) of known, measured volume (194.5 cc) was filled with ^{99m}Tc-pertechnetate in water (0.033 mCi/ml) and placed within a torso phantom. No activity was added to the torso phantom (torso filled with water with no activity, lung inserts filled with air). Tomographic images were acquired using the same imaging system, with acquisition parameters and collimators as described below for the TMUGA patient studies.

The projection data were reconstructed with two-dimensional Wiener filter defined as:

$$W(u,v) = MTF(u,v)^{-1} \times MTF^2(u,v)/[MTF^2(u,v)$$
$$+ N(u,v)/P(u,v)],$$

where u and v are spatial frequencies expressed as cycles per mm, N is the noise power spectrum, P is the object power spectrum and MTF is the modulation transfer function computed from the line spread function. The noise power spectrum N was assumed to have a constant average value of its power spectrum equal to the total image count. The object power spectrum P was taken to be the image power spectrum minus the total image count. The second term to the right of the equal sign is the low-pass filter whose roll-off is dependent on the magnitude of the ratio of the noise to object power spectrums compared to the square of the MTF (19). Using a cylindrical phantom filled with water (22 cm diameter, 22 cm length) and a line source placed in the center, the tomographic resolution was determined to be 11.7 mm at FWHM. By calculating volumes at different threshold levels, a 37% threshold was found to be most accurate. This value is similar to values determined in previous studies using the threshold method (14–16).

Radionuclide First-Pass Scintigraphy

Twenty minutes before radionuclide injection, patients received 15 μg/kg stannous pyrophosphate intravenously. First-pass images were acquired in the 30° RAO position after rapid bolus injection of 20–25 mCi of ^{99m}Tc-pertechnetate in approximately 0.1 cc followed by a large-volume (approximately 30 cc) saline flush. Images were acquired using a 64 × 64 matrix with a 24 time frame ECG gating. FP data were analyzed with commercially supplied software using standard techniques (GE Medical Systems).

Planar Gated Blood-Pool Scintigraphy

Conventional planar MUGA (PMUGA) was obtained in the best septal LAO projection for 7 million counts or 10 min with low-energy high-resolution parallel-hole collimators (LEHRP), 128 × 128 matrix, 16 time frame ECG gating, and 15% R-R

FIGURE 1. (Left) Transaxial slice of the phase image. The LV is in the upper right and the RV is in the upper left corner. A ROI is drawn to separate LV from LA. (Middle) ROI from phase image (left) superimposed on corresponding transaxial end-diastolic slice. (Right) ROI manually drawn on the thresholded image with ventricular separation guided by boundaries from the previous two panels.

interval acceptance window. LV EF was calculated semiautomatically with commercially available software (GE Medical Systems).

Tomographic Gated Blood-Pool Scintigraphy

Images were acquired on a triple-headed gamma camera (Picker Prism 3000) using LEHRP collimators and the following acquisition parameters: 3°/stop (40 stops over 120° per head) for 360°, 40 heart beats/stop, 15% R-R interval acceptance window, 16 gated intervals, 64 × 64 matrix, and image magnification of 1.422. Images were reconstructed as described above in the phantom study. Voxel size for these parameters is 0.125 cc/voxel.

The end-systolic (ES) and end-diastolic (ED) volumes were extracted from the reconstructed TMUGA data. These volumes were determined by visually inspecting all volumes in cine display. ED and ES were confirmed by determining the maximum and minimum pixel values within the left ventricle. These volumes were then thresholded at 37% of the peak left ventricular activity from the four-dimensional dataset.

The time-activity curve of each voxel was fitted to the first Fourier transform harmonic. This is analogous to the two-dimensional operation performed for PMUGA. From the four-dimensional TMUGA images, three-dimensional parametric phase and amplitude images were derived using a least-squared error-fitting routine.

End-diastolic and end-systolic volumes were displayed simultaneously with the phase and amplitude images before thresholding in order to preserve anatomical relationships with lower intensity structures. All ROIs were drawn on transaxial images. First, ROIs were drawn on the phase images to define the boundary between left atrium and left ventricle. Next, these ROIs were superimposed on the end-diastolic and end-systolic volumes to guide the operator in ROI placement on the thresholded images. Finally, ROIs were manually drawn on the thresholded images using: (a) the thresholded intensity as the ventricular free border boundary; (b) the phase image to separate atrial and ventricular regions; and (c) visual inspection to define the interventricular septum. The steps used in defining regions of interest are shown in Figure 1. Volumes were defined by the sum of all selected pixels within each slice and summed for all slices (Simpson's rule). The LV EF was calculated from the Simpson's rule method and by the change in count method (change in total counts within the regions at end-diastole and end-systole, divided by total end-diastolic counts). Several transaxial slices at end-diastole and their corresponding slices at end-systole are shown in Figure 2.

Right ventricular volumes were similarly defined. The right atrium and right ventricle were separated using the same phase analysis procedure used to separate left atrium and left ventricle. At the pulmonary valve plane, the phase image also represented translational motion. Therefore, the pulmonary valve plane was defined with respect to adjacent structures. This plane was defined at 1 transaxial slice above the superior border of the left ventricle at end-diastole. When viewed in cine format, visual estimation of the valve plane confirms that this level is appropriate. This method
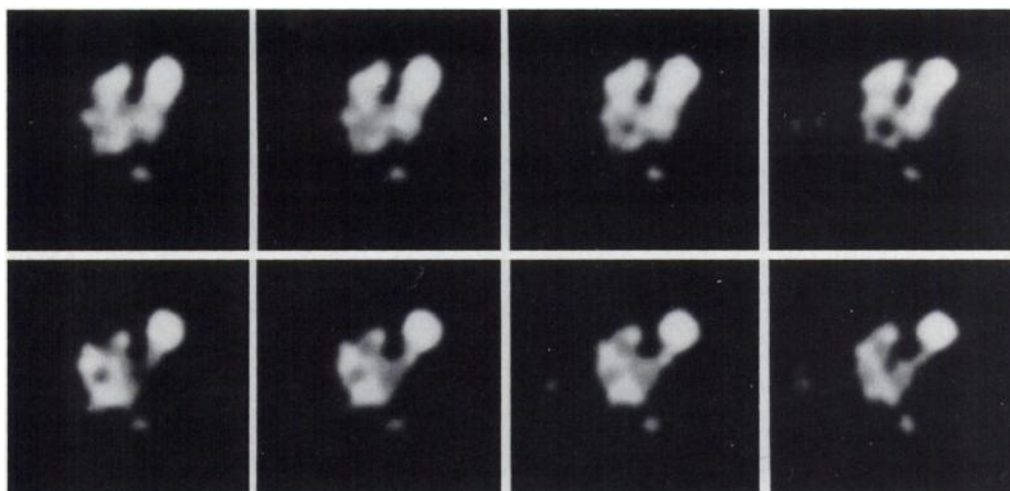
FIGURE 2. (Top row) Midventricular transaxial end-diastolic images from the same patient in Figure 1 (same orientation). Left slices are superior; right are inferior. (Bottom row) Corresponding midventricular transaxial end-systolic slices. Note good basal contraction and progressive apical aneurysmal dilation. The LV apical dyskinesis is out of phase as shown in Figure 1 (left).

was easily reproducible and the absolute RV volume error in the RV outflow tract was felt to be relatively small compared to the total RV volume. Image display and ROI analysis were performed with a general-purpose software package developed within the institution (Petview 1.1).

Gated Cine MRI

MRI images were acquired on a 1.5 Tesla MRI system (GE) using a fast, gradient-echo, ECG-gated, pulse sequence. At each slice location, 8–12 cardiac phases were acquired from end-diastole through end-systole during a breath-hold. All subjects were given careful instructions on how to suspend respiration at end-expiration. Twelve to fifteen short-axis (SA) images were acquired from the pulmonary valve plane to the LV apex. The imaging parameters were: field of view = 24–26 cm, flip angle = 30°, slice thickness = 6 mm, interslice spacing = 2mm, TR/TE = 7.2/2.6 msec. Representative short axis slices at end-diastole and end-systole are shown in Figure 3.

Analysis was done with customized software (SPAMMVU) (20) using a semiautomatic contour tracking routine. This method models each contour as an analytic function with an associated effective strain "energy." The contours are automatically attracted to edges in the image, but they can be manipulated by the user to outline regions with poor contrast or to avoid artifacts. Internal stiffness of the model results in smoothing and fast outlining, typically taking less than 20 min per study. All volumes were computed using Simpson's rule. MRI-measured volumes of static phantoms using these methods had less than 5% error compared to known measurements. Previous validation in normal human vol-

unteers showed excellent correlation of LV stroke volume (SV) compared to RV SV (r = 0.92) (21).

Statistical Analysis

Simple linear regression was used to compare ejection fractions and volume measurements between TMUGA, MRI, FP and PMUGA. Variability about the regression line was expressed as the standard error of the estimate (s.e.e.). Group values for samples were expressed as mean ± 1 s.d. Paired comparisons of ventricular ejection fraction and volumes between FP, PMUGA, TMUGA and MRI were performed with paired Student's t-test. Differences between measurement methods were expressed as mean ± 1 s.e.m. (1SEM). Statistical analyses were performed with the commercial software package JMP (SAS Institute).

RESULTS

Comparison of Tomographic Methods: Right and Left Ventricular Volumes and Ejection Fractions

Overall, for right ventricular ES and ED volumes, TMUGA demonstrated good correlation (r = 0.91) with MRI (Fig. 4). In subgroup analysis of these 10 patients, the right ventricular ED volume by TMUGA (mean = 108 ± 24, range = 84–154) was not significantly different (p = 0.18) compared to MRI (mean = 99 ± 27, range = 66–167). The mean right ventricular ES volume by TMUGA (mean = 54 ± 25, range = 28–102) was greater than that for MRI (mean = 46 ± 24, range = 24–100), however, a statistically significant difference could not be demonstrated (p = 0.06).
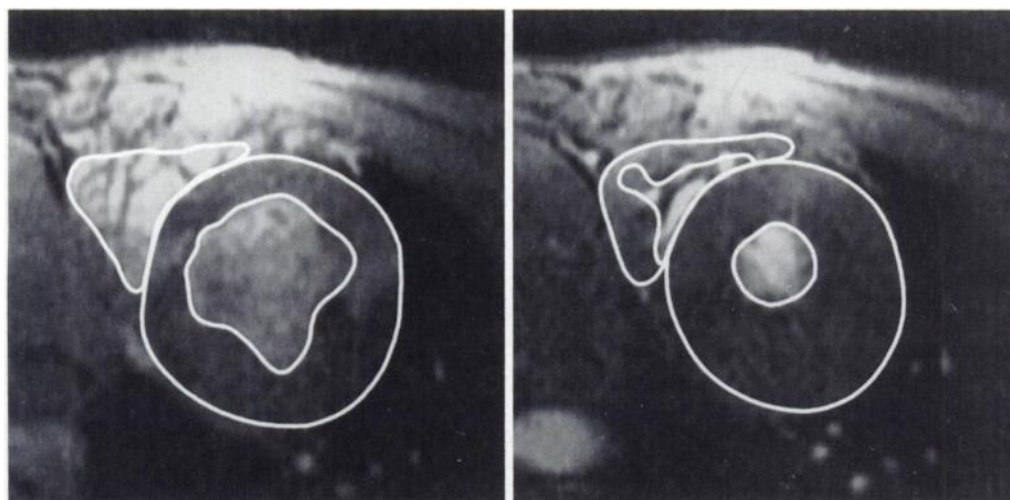

FIGURE 3. Short-axis gradient-echo breath-hold MR images of the left ventricle. Midventricular slices at (left) end-diastole and (right) end-systole. (Lower right contour) Contours for the left and (upper left contour) right ventricles are superimposed on these images.
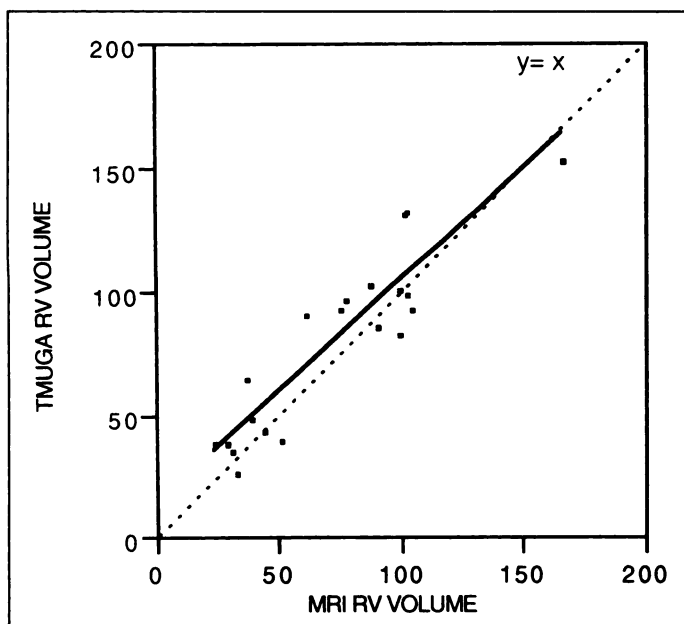
FIGURE 4. TMUGA versus MRI right ventricular volumes at end-diastole and end-systole for 10 patients (n = 20, r = 0.91, slope = 0.90, intercept = 15.7, s.e.e. = 15.7).

FIGURE 6. Right ventricular ejection fraction by TMUGA versus MRI for 10 patients (r = 0.88, slope = 0.79, intercept = 8.4, s.e.e. = 6.0).

The left ventricular volumes showed similar results. Overall, left ventricular ED and ES volumes by TMUGA provided excellent correlations (r = 0.96) with MRI (Fig. 5). For 10 patients, the left ventricular ED volume by TMUGA (mean = 143 ± 52, range = 88–243) was not significantly different (p = 0.78) compared to MRI (mean = 144 ± 67, range = 74–261). For left ventricular ES volumes, TMUGA measurements (mean = 84 ± 64, range = 24–194) were not significantly different (p = 0.26) compared to those by MRI (83 ± 63, range = 19–187).

For right ventricular ejection fraction, TMUGA revealed a good correlation (r = 0.88) with MRI (Fig. 6); however, most of the patients in this group had values in the normal range. Left ventricular ejection fractions showed a better correlation (r = 0.94) and included patients with a wider range of function (Fig.
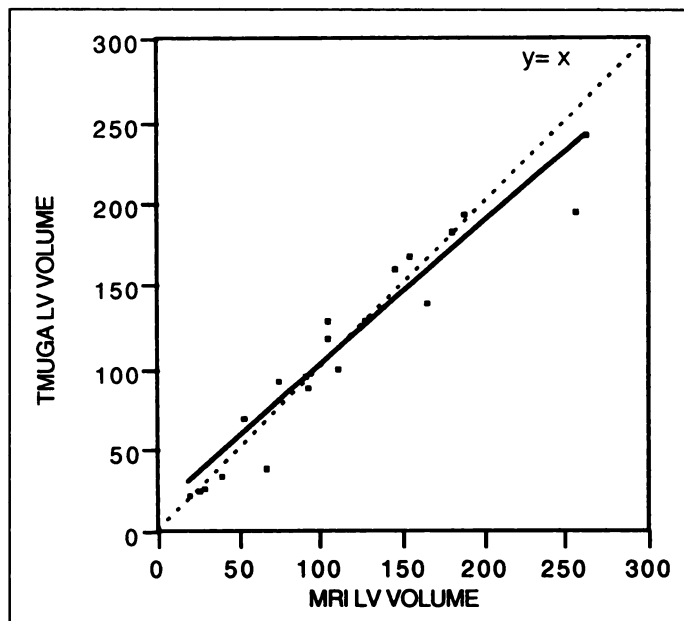
7). The right ventricular ejection fraction computed from Simpson's rule and from total counts showed an excellent correlation (r = 0.99, Fig. 8). Similarly, the left ventricular ejection fraction computed by either method (r = 0.99) demonstrated essentially the same results (Fig. 9).

Comparison of Tomographic and Planar Methods: Right and Left Ventricular Ejection Fractions

Right ventricular ejection fraction by TMUGA demonstrated good correlation (r = 0.86) with FP (Fig. 10) scintigraphy. There was no detectable difference in RVEF by TMUGA and FP (p = 0.76) or between TMUGA and MRI (p = 0.16).

Left ventricular ejection fraction by TMUGA showed an excellent correlation (r = 0.96) with PMUGA over a wide range of function (Fig. 11). The left ventricular ejection fractions by both tomographic methods (MRI and TMUGA) were higher

FIGURE 5. TMUGA versus MRI left ventricular volumes at end-diastole and end-systole for 10 patients (n = 20, r = 0.96, slope = 0.88, intercept = 14.1, s.e.e. = 18.2).

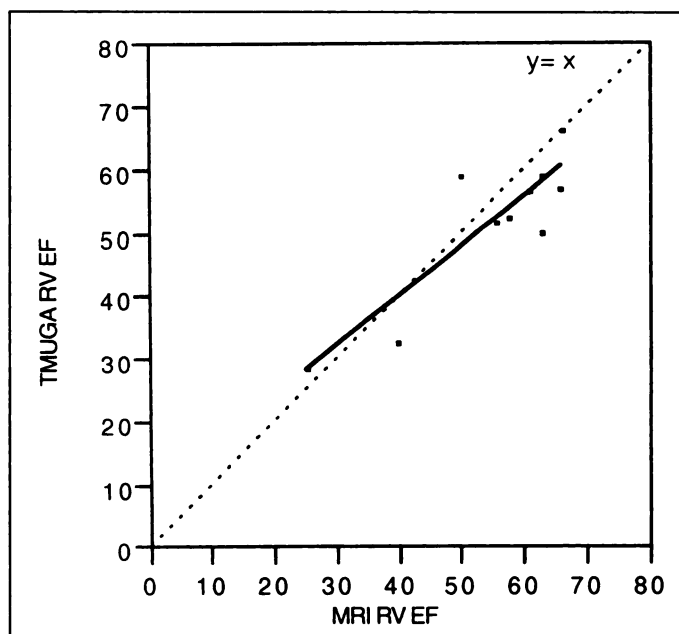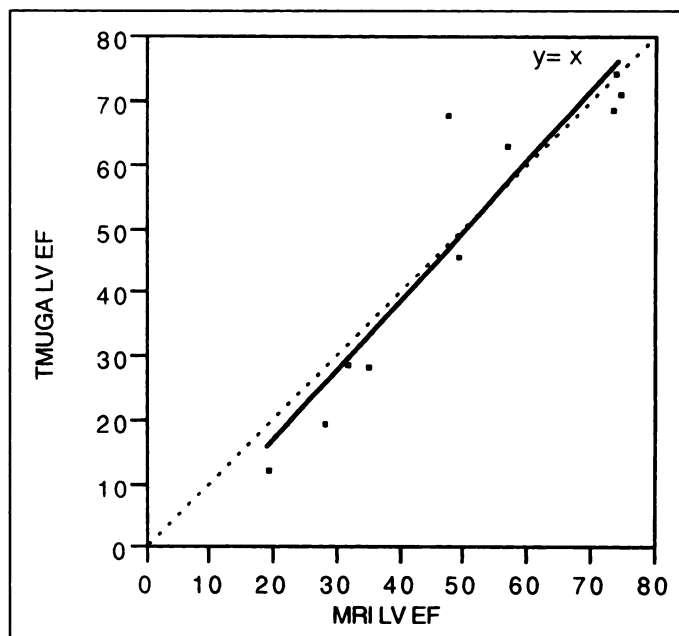FIGURE 7. Left ventricular ejection fraction by TMUGA versus MRI for 10 patients (r = 0.94, slope = 1.1, intercept = −5.6, s.e.e. = 9.0).
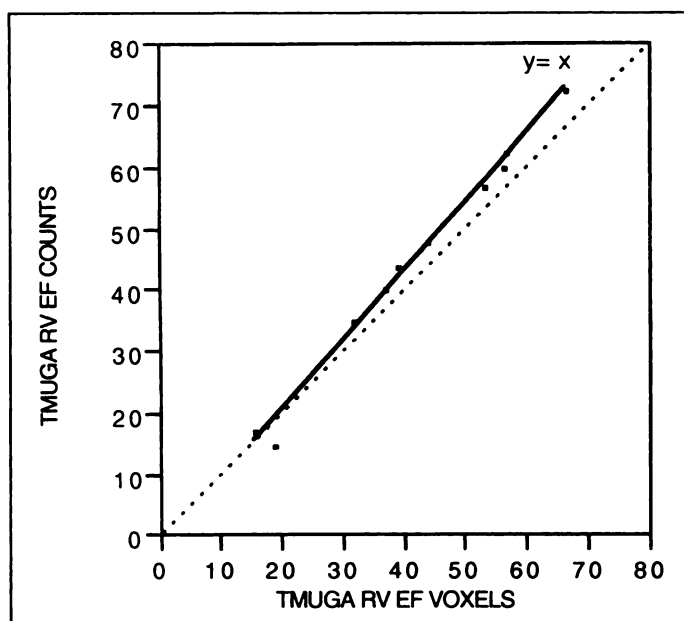
FIGURE 8. Right ventricular ejection fraction by counts versus pixels for 10 patients (r = 0.99, slope = 1.1, intercept = -2.3, s.e.e. = 2.0).

FIGURE 10. Right ventricular ejection fraction by TMUGA versus FP for 10 patients (r = 0.86, slope = 1.2, intercept = -8.3, s.e.e. = 7.9).

than by planar MUGA. The left ventricular ejection fraction by TMUGA (52.6 ± 23.8, range = 12–85, n = 18) was significantly (p < 0.01) greater than that by PMUGA (46.5 ± 19.0, range = 17–70, n = 18). Similarly, left ventricular ejection fraction by MRI (49.3 ± 20.4, range = 20–75, n = 10) was also significantly (p < 0.01) greater than that by PMUGA (42.2 ± 18.9, range = 17–68, n = 10). TMUGA LV EF (mean 48.5 ± 23.9, range = 12–75, n = 10) was not significantly different (p = 0.78) from MRI LV EF (mean 49.3 ± 20.4, range = 20–75, n = 10).

STUDY LIMITATIONS

Patient background activity may affect the threshold value used to define the ventricular free-wall boundary, but the magnitude and overall effect are difficult to predict. High patient background activity res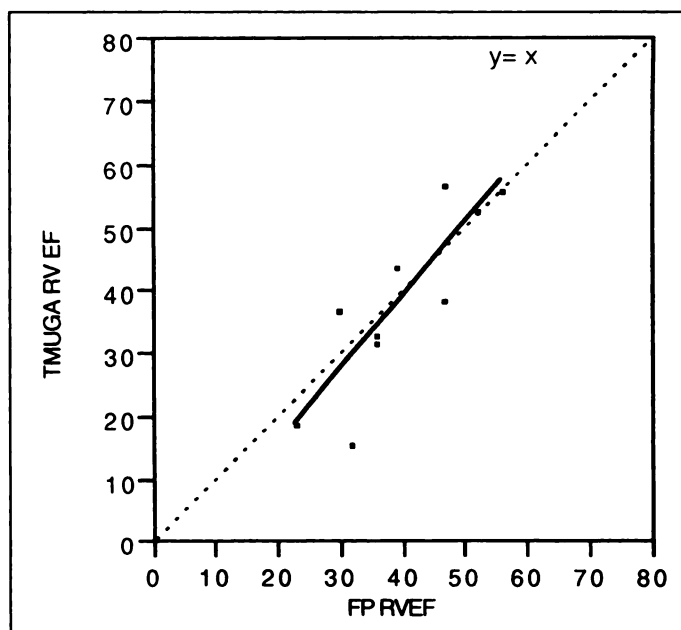ults in higher counts adjacent to the ventricular boundary and within the ventricle due to additional scatter. Additional voxels at the ventricular boundary may be included due to higher counts and, therefore, result in an overestimation of the ventricular volume. However, the threshold value is calculated as a percentage of peak activity within the chamber. An increase in scatter also may increase the peak ventricular activity and, therefore, it may also increase the absolute threshold value. This would tend to decrease the overestimation in volume caused by inclusion of the additional voxels at the ventricular boundary. As background becomes very high, the effect of including additional voxels at the ventricular boundary may become greater than the latter effect, possibly resulting in an overestimation of ventricular volume. Without further study, an attempt to compensate for background may introduce additional measurement error.
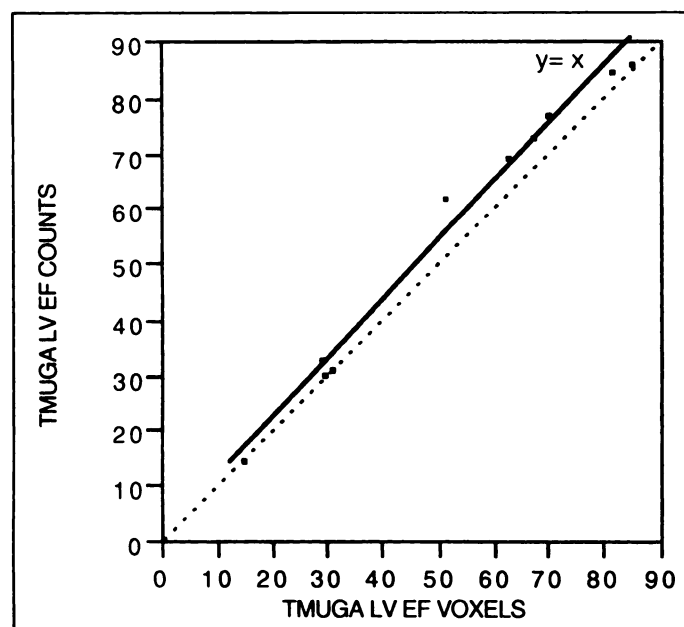

FIGURE 9. Left ventricular ejection fraction by counts versus pixels for 10 patients (r = 0.99, slope = 1.1, intercept = 0.9, s.e.e. = 3.5).
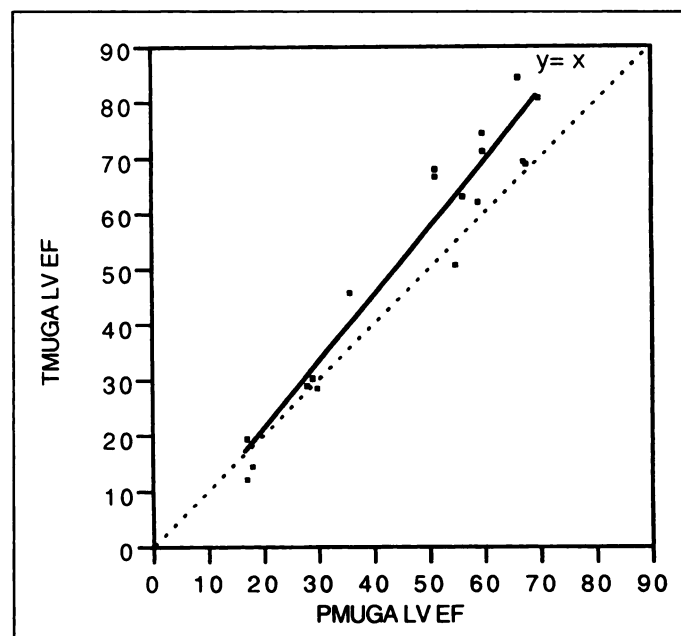

FIGURE 11. Left ventricular ejection fraction by TMUGA versus PMUGA for 18 patients (r = 0.96, slope = 1.2, intercept = -3.7, s.e.e. = 6.7).

In our patient studies, high background activity was not subjectively evident. The planar first-pass and planar gated blood-pool studies were obtained before the tomographic gated blood-pool study, requiring approximately 30 min. During this time, some of the ^{99m}Tc-pertechnetate is filtered through the kidneys. SPECT imaging also increases contrast. These factors contributed to the relatively low background activity.

In defining ventricular boundaries, we visually integrated threshold, phase and septal boundary information. This was necessary because of the complexity required to define an automated algorithm that would accurately apply different boundary criteria at different locations in each transaxial slice. More sophisticated techniques for boundary definition may improve the reproducibility and accuracy of volume measurements. Further study in a larger patient population is required to validate the interoperator and intraoperator variability of these measurements.

The number of patients with right ventricular dysfunction was greater in the subset of patients with FP and TMUGA (Fig. 10) compared to those with MRI and TMUGA (Fig. 6). This lessened the strength of association between right ventricular ejection fraction measurements by TMUGA and MRI. No single factor could be identified that explains this difference in the subset of patients who had FP and MRI. One possible contributing factor may have been the inability or unwillingness of volunteers with severe lung disease or claustrophobia to undergo MRI evaluation. Further study is required to conclude that right ventricular ejection fraction by TMUGA is not significantly different compared to MRI over a wide range of values. However, other comparisons suggest that TMUGA right ventricular measurements may prove to be accurate. TMUGA right ventricular volumes did show good correlations with MRI over a wide range of values (Fig. 4). Also, TMUGA right ventricular ejection fraction showed good correlation with FP over a wide range of values (Fig. 10).

Although ventricular volume measurements by MRI have shown good reproducibility, variability in MRI measurements also exist. Factors that may influence variability include: differences in breath-hold images at end-inspiration due to variability in the extent of inspiration; variability in contouring; variability due to the curvature through imaging planes; partial volume errors; and interobserver and intraobserver variabilities in defining contours.

DISCUSSION

Accurate assessment of ventricular function is a primary objective in the evaluation of coronary artery disease, valvular stenosis and regurgitation, and right- and left-sided heart failure. Recently, validations of MRI volumes and ejection fractions have provided a more appropriate tomographic gold standard for comparison with TMUGA. Previous studies have shown that tomographic gated blood-pool scintigraphy (TMUGA) has provided good measurements of left ventricular volumes and ejection fractions when compared to conventional contrast angiography (14–16,22,23). Absolute right ventricular volume measurements by TMUGA have not been previously reported (14–16,22,23).

Absolute volume and ejection fraction measurements showed good correlations with established techniques. The TMUGA right ventricular volumes and ejection fractions demonstrated good correlations with both MRI and FP methods. The right ventricular measurements revealed more variability than those for the left ventricle. Because of the complex geometry of the right ventricle, both MRI and TMUGA right ventricular volume measurements are likely to be less accurate than those for the

left ventricle. MRI inter- and intraoperator variability for volume and ejection fraction measurements are greater for the right ventricle than for the left ventricle (11–13). Operator subjectivity in defining the right ventricular endocardial borders by MRI was reported as a significant factor contributing to this variability (13).

Right ventricular ejection fraction by TMUGA did not show any significant difference compared to the FP. A statistically significant difference between these methods may be more difficult to detect when larger variabilities in right ventricular measurements occur. However, our results agree with a previous validation of gated FP that showed no significant difference in right ventricular EF compared to ultrafast electron beam CT (24). The gated FP radionuclide method also may be less susceptible to the underestimation of right ventricular EF because overlapping structures of the left heart do not have activity during FP data acquisition. The FP radionuclide method has shown good reproducibility for right ventricular ejection fraction. However, poor intravenous access in chemotherapy patients, poor quality bolus in patients with severe heart failure and poor counting statistics are technical limitations to this method. In addition, the FP technique cannot accurately measure absolute right ventricular volumes.

The TMUGA left ventricular volume and ejection fraction measurements also showed excellent correlations to MRI and conventional PMUGA. Both TMUGA and MRI left ventricular ejection fractions were significantly higher than those by PMUGA. One possible explanation is that PMUGA does not completely separate overlapping activity from the right ventricle or the left atrium. This may result in a smaller true difference in total counts and, consequently, a lower ejection fraction. When comparing MRI and TMUGA, LV EF measurements were not statistically different. Similarly, MRI and TMUGA left ventricular volumes also showed no statistically significant difference.

Advances in multidetector cameras, software and processing algorithms have facilitated rapid data acquisition and processing of tomographic MUGA. The acquisition time for tomographic MUGA on a multidetector system is now approximately the same or less than a conventional three-view planar MUGA study acquired on a single-detector system. In addition to absolute ventricular volume and functional information, tomography separates overlapping structures which facilitates better visualization of wall motion. This improves accuracy in detection and characterization of wall motion abnormalities when compared to planar techniques (14).

In summary, right and left ventricular volumes and ejection fractions by tomographic gated blood-pool scintigraphy showed good correlation with established techniques. Further studies are required to define the reproducibility of the ventricular volume measurements and the parameters derived from these volumes.

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Ambulatory Monitoring of Left Ventricular Function: Walk and Bicycle Exercise in Congestive Heart Failure

Antonio Nappi, Alberto Cuocolo, Massimo Imbriaco, Emanuele Nicolai, Andrea Varrone, Carmine Morisco, Massimo Romano, Bruno Trimarco and Marco Salvatore
Nuclear Medicine Center of the National Council of Research (CNR) and Internal Medicine, University "Federico II," Napoli, and Mediterranean Institute of Neurosciences, "Sanatrix," Pozzilli, Italy

The aim of this study was to assess changes in left ventricular (LV) function during 6-min walk test and cardiopulmonary exercise by continuous radionuclide monitoring in patients with congestive heart failure (CHF). **Methods:** Seventeen patients with CHF and 10 normal subjects underwent monitoring of LV function (Vest) during 6-min walk test and during bicycle exercise with combined analysis of pulmonary gas exchange. During cardiopulmonary exercise, all parameters of LV function were measured at rest, at the anaerobic threshold (AT) and at peak oxygen uptake (peak VO_2). **Results:** In the normal subjects, during the walk test, heart rate (HR), ejection fraction (EF), end-diastolic volume (EDV), cardiac output (CO) and stroke volume (SV) significantly increased from rest to peak (all p < 0.001), while end-systolic volume (ESV) significantly decreased from rest to peak (p < 0.001). In patients with CHF, during the walk test, HR, EDV, ESV and CO significantly increased from rest to peak (p < 0.001), EF significantly decreased from rest to peak (p < 0.001) and SV did not show significant change. During cardiopulmonary exercise, normal subjects showed a significant increase in HR and CO, from rest to AT and from AT to the peak VO_2 (p < 0.001). EF, EDV and SV significantly increased from rest to AT (p < 0.001), with no significant change from AT to peak VO_2. ESV decreased from rest to AT (p < 0.001), showing no significant change from AT to peak VO_2. In patients with CHF, HR, CO, ESV and EDV increased significantly

from rest to AT (p < 0.001) and from AT to peak VO_2 (p < 0.001). EF and SV did not show significant changes from rest to AT, showing a significant decrease from AT to peak VO_2 (p < 0.001). **Conclusion:** Vest can be used to evaluate cardiac responses during 6-min walk test and cardiopulmonary exercise in patients with CHF. In such patients, significant impairment of LV function is already present during submaximal physical exercise becoming more evident during the anaerobic phases of bicycle exercise.

Key Words: Vest; physical exercise; left ventricular dysfunction; congestive heart failure

Congestive heart failure (CHF) is a major health problem. In the U.S. CHF is responsible for more than 900,000 hospitalizations a year and 37,000 deaths a year (*1*). Functional capacity in patients with CHF has been measured using the New York Heart Association (NYHA) criteria (*2*). However, this approach provides a subjective and semiquantitative evaluation of these patients. Therefore, objective and reliable techniques allowed to assess the severity of left ventricular (LV) dysfunction and the response to the therapy are essential for the optimal clinical management of patients with CHF. The 6-min walk test has been widely used in the evaluation and serial assessment of patients with chronic respiratory disorders (*3*). However, experience in patients with CHF is more limited (*4,5*). Although this