Assessment of right ventricular function using two-dimensional echocardiography

With the use of two-dimensional echocardiography (2DE), we analyzed apical and subcostal four-chamber views for evaluation of right ventricular (RV) function in 30 individuals as compared to RV ejection fraction (RVEF) obtained by radionuclide angiography. In addition to previously reported parameters of changes in areas and chords, a new simple measurement of tricuspid annular excursion was correlated with RVEF. A close correlation was noted between tricuspid annular plane systolic excursion (TAPSE) and RVEF ($r = 0.92$). The RV end-diastolic area (RVEDA) and percentage of systolic change in area in the apical four-chamber view also showed close correlation with RVEF ($r = -0.76$ and 0.81); however, the entire RV endocardium could only be traced in about half of our patients. The end-diastolic transverse chord length and the percentage of systolic change in chord length in the apical view showed a poor correlation with RVEF. The correlation between RVEF and both areas and chords measured in the subcostal view was poor. It is concluded that the measurement of TAPSE offers a simple echocardiographic parameter which reflects RVEF. This measurement is not dependent on either geometric assumptions or traceable endocardial edges. When the endocardial outlines could be traced, the apical four-chamber view was superior to the subcostal view in assessment of RV function. (Am Heart J 107:526, 1984.)

Sanjiv Kaul, M.D.,* Chuwa Tei, M.D., James M. Hopkins, B.S., and Pravin M. Shah, M.D. *Los Angeles, Calif.*

An accurate assessment of right ventricular (RV) function has been difficult, although biplane ventriculography has been utilized in the past. Apart from being tedious, this method assumes geometric shapes for measuring ventricular volumes and ejection function and has not gained popularity as a routine method.[1-6] In recent years, radionuclide angiography has been employed as a standard method for the determination of RV function. First-pass studies[7,8] and, more recently, multiple-gated studies[9,10] have been shown to accurately reflect RV function.

Although two-dimensional echocardiography (2DE), which offers better image orientation and real-time capability, has achieved widespread use in the determination of left ventricular function,[11] its role in the assessment of RV function has yet to be defined. This study was initiated to investigate the role of measuring RV cross-sectional areas and chords in the assessment of RV function. A chance observation on the RV annular motion suggested its possible role in evaluating RV systolic function. This article is a systematic correlation of this simple parameter and the more elaborate cross-sectional area measurements to RV ejection fraction (RVEF) as measured by radionuclide angiography.

METHODS

Patients. Thirty male individuals were included in this study. Ten normal subjects (age 31.7 ± 1.3), selected on the basis of having adequate recording of the right ventricle for the purposes of quantitative data analysis, constitute group 1. These subjects had no history of cardiovascular disease and were found to be normal by physical examination and ECG and echocardiographic recordings. Twenty patients with documented coronary artery disease were divided into two groups. Group 2 (age 60.7 ± 3.1) consisted of 10 patients with previous inferior wall myocardial infarction and group 3 consisted of 10 patients with previous anterior myocardial infarction (age 60.5 ± 2.8). All patients in group 2 and 8 of 10 in group 3 had previous cardiac catheterization with selective coronary angiography. All of these patients underwent 2DE and radionuclide studies within 48 hours of each other. Tech-

From the Department of Medicine, University of California School of Medicine, and Wadsworth VA Medical Center.

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Reprint requests: Pravin M. Shah, M.D., Cardiology (691/111E), Wadsworth VA Medical Center, Wilshire and Sawtelle Blvds. Los Angeles, CA 90073.

*Current address: Cardiac Unit, Massachusetts General Hospital, Boston, MA 02114.

nical quality of echocardiograms was not used as a criterion for patient selection. Thus no patient was excluded because of inability to adequately image the right ventricle.

Radionuclide studies. All of the 20 patients with coronary artery disease underwent multiple-gated equilibrium blood pool imaging for assessment of RV function. In vivo red cell labeling was accomplished by intravenous administration of 7.5 mg stannous pyrophosphate followed 15 to 20 minutes later by 25 mCi of technetium-99m pertechnetate. Five minutes were allowed for equilibration following which all patients were studied in the 45-degree left anterior oblique projection with caudal tilt to maximize chamber separation. Data were acquired over a 2-minute period at 14 frames/cycle. An Ohio Nuclear series 120 portable scintillation camera with a high-sensitivity collimator was used for acquiring data. This was interfaced to a Medical Data Systems PAD computer equipped with hardware zoom set at 1.5 magnification. A Brattle ECG gate was used.

Echocardiographic studies. All individuals were studied in both partial left lateral decubitus and supine positions. A commercially available system with a 2.25 MHz transducer was used for recording images on a one-half inch tape cassette Sony video recorder. This recorder has the capability for playback in real-time, slow-motion (frame by frame), and stop-action modes. Apart from the standard long- and short-axis views, apical four-chamber and subcostal views were obtained for quantitative analysis of RV function.

Radionuclide data analysis. The technique described by Maddahi et al.[10] was used to determine RVEF. This required light pen assignment of regions of interest over the right ventricle in both end diastole and end systole. These frames were determined from a time-activity curve generated over the right ventricle. For background, a paraventricular area just outside the left ventricle was selected in the end-systolic frame. This was approximately four matrix elements wide. The data were then displayed on an endless movie format at 14 frames/cycle to allow appreciation of the planes of separation of the right ventricle from the right atrium and pulmonary artery. RVEF was assessed in the conventional manner as (end-diastolic counts − end-systolic counts)/end-diastolic counts.

Echocardiographic data analysis. Apical four-chamber and subcostal four-chamber views were analyzed. Only technically adequate data were processed. Data were considered technically adequate if no dropouts in the endocardial outlines along the interventricular septum and RV free wall were observed. End-diastolic and end-systolic frames were selected from the same cardiac cycle by means of the stop-action mode. The endocardial edges of the right ventricle and the plane of the tricuspid valve were traced on a clear plastic sheet in each frame. From the center of origin of the echocardiographic fan, a line was drawn to the junction of the tricuspid valve with the RV free wall. In end-systole, the plane where the tricuspid anulus dissected this line was marked (Fig. 1). The

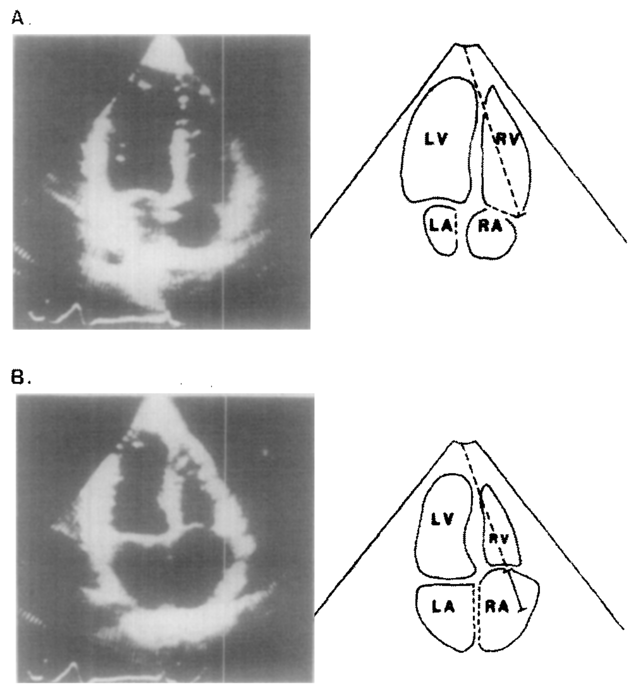

Fig. 1. Demonstration of method of measuring TAPSE in apical four-chamber view. *A*, Straight line is drawn from midpoint of origin of echocardiographic fan to junction of RV free wall and tricuspid valve in end diastole. *B*, In end systole the plane of the tricuspid valve is seen to dissect the line drawn in end diastole. Solid line depicts TAPSE.

following measurements were then made: (1) excursion of the tricuspid valve plane from end diastole to end systole in the four-chamber view (tricuspid annular plane systolic excursion [TAPSE]); (2) end-diastolic area in both views; (3) end-systolic area in both views; (4) midcavity chord length at end diastole in both views; and (5) midcavity chord length at end systole in both views.

For both subcostal and apical views, changes in RV areas were expressed as percentage of change in area and calculated by means of the formula (end-diastolic area − end-systolic area)/end-diastolic area × 100. The changes in midcavity transverse chord lengths were also expressed as percentage of change in chord length and calculated by means of the formula (end-diastolic chord length − end-systolic chord length)/end-diastolic chord length × 100. The inter- and intraobserver variability was examined for measurement of systolic excursion of the tricuspid annular plane and the RV area measurements.

Statistics. All data were expressed as mean ± 1 SD. Inter- and intraobserver variability was analyzed by linear regression analysis. This method was also used to compare data acquired from apical and subcostal four-chamber views. Linear regression analysis was also used to compare echocardiographic criteria for the assessment of RV function with RVEF measured by radionuclide angiography. The group data were compared by means of analysis of

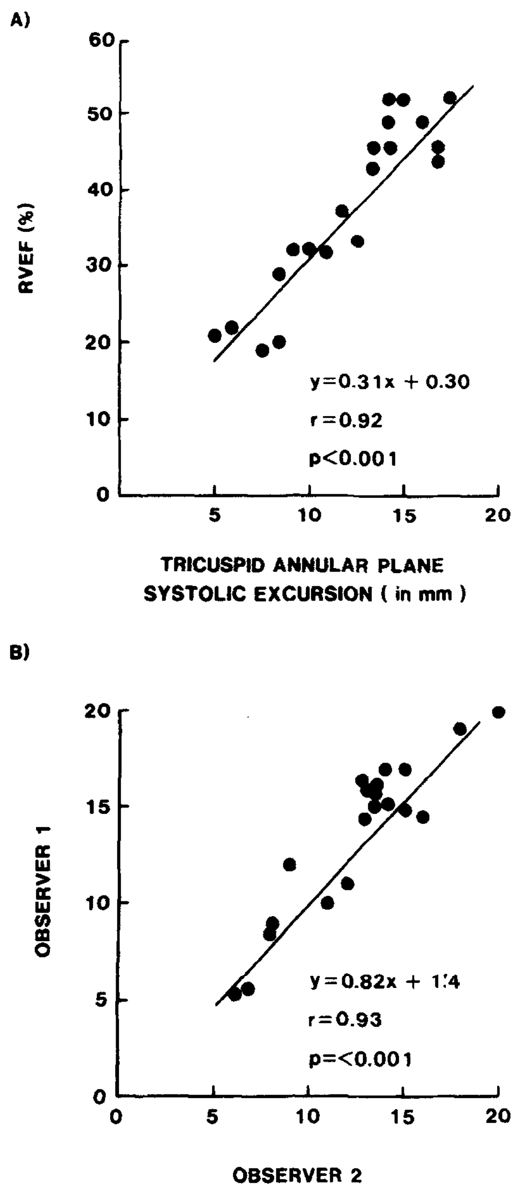

Fig. 2. *A*, Correlation of RVEF as measured by radionuclide blood pool imaging with TAPSE. *B*, Demonstration of interobserver variability in measuring systolic excursion of tricuspid annular plane.

variance and the difference in group means was considered significant at $p < 0.05$.

RESULTS

Radionuclide data were adequate in all individuals studied. Inter- and intraobserver variability for the assessment of RVEF by means of multiple-gated radionuclide angiography was determined in our laboratory. The r value for interobserver variability was 0.93 (n = 20, $p < 0.001$) and for intraobserver variability was 0.98 (n = 15, $p < 0.001$). Endocardial tracings of the right ventricle could be made in the apical four-chamber view in 10 of 10 normal subjects, since this was used as a selection criterion for the normal subjects and 12 of 20 patients with coronary artery disease. The interobserver and intraobserver reproducibility for these measurements was close ($r = 0.93$ and 0.98, respectively, n = 20, $p < 0.001$). In 9 of 10 normal subjects, the RV endocardium could be traced in the subcostal view while it could be traced in 10 of the 20 with coronary artery disease. In four patients neither view could be traced while in six both views could be traced. The junction of the tricuspid annular plane and RV free wall could be identified in all individuals. Fig. 1 illustrates our technique of measuring tricuspid annular plane excursion. Table I provides a summary of the data.

Comparison of RVEF and TAPSE. A close correlation between RVEF and TAPSE was observed ($r = 0.92$, n = 20, $p < 0.001$). Interobserver reproducibility of TAPSE was close ($r = 0.93$, n = 20, $p < 0.001$). According to the linear regression equation RVEF by radionuclide angiography = 3.2 × TAPSE in mm (see Fig. 2). There was a significant difference in the systolic excursion between groups 1 and 2 ($p < 0.001$) being 16.3 ± 0.6 in group 1 and 9.0 ± 0.8 in group 2. There was no statistically significant difference between groups 1 and 3.

Comparison of RVEF and dimensions obtained in the apical view. There was close correlation between RVEF measured by radionuclide angiography and RV end-diastolic area (RVEDA) ($r = -0.76$, n = 12, $p < 0.001$), and between RVEF and percentage of systolic change in area ($r = 0.81$, n = 12, $p < 0.001$) (Fig. 3). The RVEDA was significantly higher in group 2 ($p < 0.01$) than in groups 1 and 3. The percentage of change in area was significantly lower in group 2 ($p < 0.01$) compared to groups 1 and 3 (Table I).

Comparison of RVEF and dimensions obtained in the subcostal view. The correlation between RVEF measured by radionuclide angiography and RVEDA measured in the subcostal view was $r = -0.21$ (n = 10, $p < 0.001$). The relationships between RVEF and percentage of change in area was $r = 0.44$ (n = 10, $p < 0.001$). There was no statistically significant difference in the RVEDA between the three groups as measured by this method while the percentage of change in area was lower ($p < 0.05$) in group 2 with the use of this method (Table I). Correlation between RVEF and RV midcavity end-diastolic chord length was poor; $r = -0.10$ (n = 10, $p < 0.001$). There was no statistically significant difference in this measurement between the three

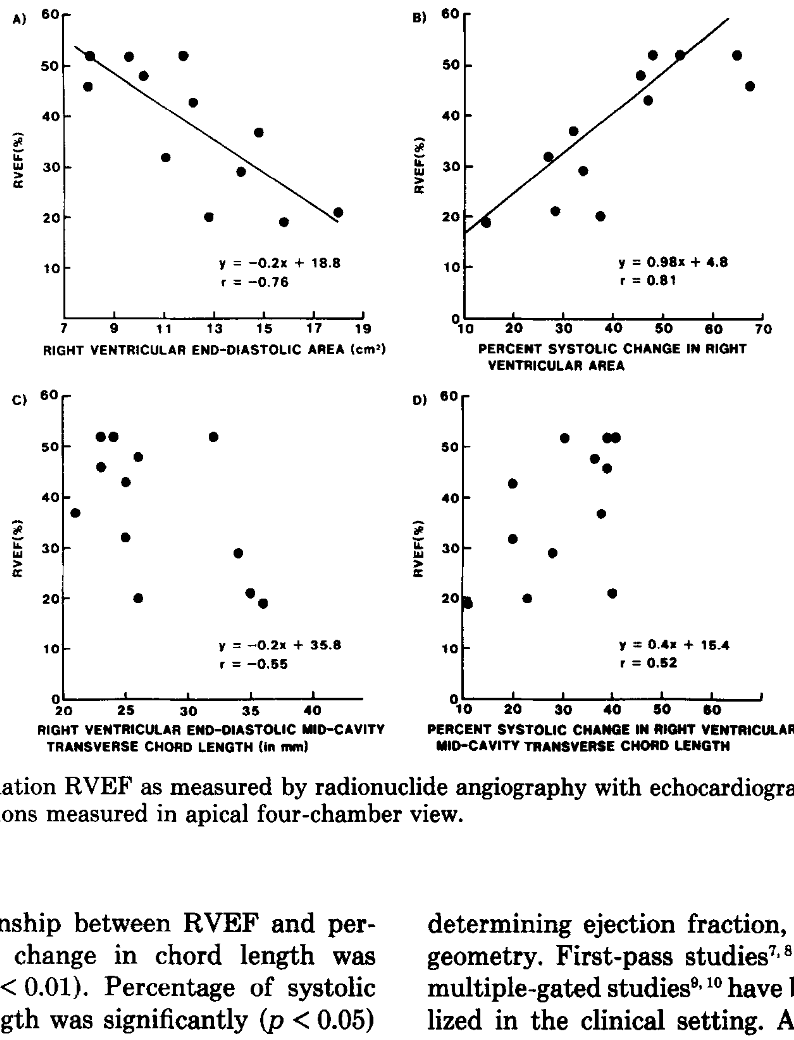

Fig. 3. Correlation RVEF as measured by radionuclide angiography with echocardiographic estimation of RV dimensions measured in apical four-chamber view.

groups. The relationship between RVEF and percentage of systolic change in chord length was $r = 0.34$ ($n = 10$, $p < 0.01$). Percentage of systolic change in chord length was significantly ($p < 0.05$) lower in group 2 (Table I).

Comparison of apical and subcostal views. In the 15 individuals in whom comparisons of these views were made, r value for end-diastolic areas in the two views was 0.35 while that for end-systolic views was 0.25. When midcavity transverse chord lengths were compared, the r values for end-diastolic and end-systolic chord lengths were 0.13 and 0.15, respectively.

DISCUSSION

Radionuclide-determined RVEF. RV geometry is complex. Different models to assess RV volumes and ejection fraction using contrast cineangiography have been reported. The approaches have utilized the Simpson equation,[4] pyramids,[5] stacks of cylinders,[4] and slices of ellipsoids.[3] There is no good geometric shape which can accurately simulate RV geometry; the results therefore depend on assumptions. In the past few years radionuclide angiographic determination of RVEF has gained prominence. Apart from being a noninvasive and rapid method of determining ejection fraction, it is independent of geometry. First-pass studies[7,8] and, more recently, multiple-gated studies[9,10] have been increasingly utilized in the clinical setting. A significant problem with this method is the separation of right atrium and pulmonary artery from the RV cavity. However, Maddahi et al.[10] were able to achieve a close correlation between RVEF obtained by first-pass technique and by this method.

RV function by 2DE. 2DE has been used to assess various aspects of left ventricular function including left ventricular ejection fraction.[11] Its use in assessment of RV function has been limited. It has been reported to provide an assessment of RV volumes[12,13] and has been shown to reliably differentiate RV volume overload from the normal right ventricle.[12] Apart from complex geometry, the assessment of RV function has been hampered by inadequate definition of the endocardium of the RV free wall. In our patient groups this was achieved in less than half the patients studied. Other obervers have reported similar difficulty.[12,13] Therefore, even computer-assisted, three-dimensional reconstruction of the ventricle would be feasible only in a minority of cases, since it is imperative to define the endocardium in multiple views. This technical limitation is

Table I. Echographic and radionuclide determinations of RV function

A. 2DE apical four-chamber view (mean ± 1 SD)

Group	*RVEF (%)*	*TAPSE*	*RVEDA*	*%Δ Area**	*RVEDCL*	*%Δ in Chord†*
1	43.3 ± 2.2	16.3 ± 0.6	10.5 ± .6	40.1 ± 2.8	2.9 ± .1	22.2 ± 2.3
2	27.9 ± 2.0	9.0 ± 0.8	14.3 ± 1.0	28.9 ± 3.3	3.0 ± .3	16.8 ± 4.5
3	47.8 ± 1.0	15.4 ± 0.5	10.0 ± 2.2	54.4 ± 3.9	2.6 ± .1	34.2 ± 3.2

B. Subcostal four-chamber view (mean ± 1 SD)

Group	*RVEDA*	*%Δ in Area**	*RVEDCL*	*%Δ in Chord†*
1	6.1 ± 0.5	58.5 ± 2.3	1.4 ± .1	48.1 ± 3.9
2	6.7 ± 0.5	47.0 ± 4.9	1.7 ± .1	35.2 ± 5.5
3	6.4 ± 0.8	56.3 ± 4.7	1.7 ± .2	42.4 ± 2.6

Abbreviations: RVEF = right ventricular ejection fraction as measured by radionuclide angiography; TAPSE: tricuspid annular plane systolic excursion; RVEDA: right ventricular end-diastolic area; RVEDCL: right ventricular end-diastolic midcavitary transverse chord length.
*Percentage of change in area between end diastole and end systole.
†Percentage of change in midcavity dimension (chord) between end diastole and end systole.

especially compounded in patients with obstructive pulmonary disease and in those with abnormal configuration of the chest wall.

The second problem that we face in assessing RV function is that RV wall motion is not similar to left ventricular wall motion. In the left ventricle all walls and the base seem to move more or less equally toward the center of mass. In the case of the right ventricle, it is the base to apex shortening which is more pronounced. This has been elegantly documented by Rushmer et al.[17]

TAPSE assessed RV function. The tricuspid valve moves toward the apex of the right ventricle during ventricular systole because of lengthwise shortening of both the interventricular septum and RV free wall. The simple measurement of TAPSE reflects this motion and is a measure of the integrity of both walls of the right ventricle. Our results demonstrate that in patients with previous inferior wall infarction (group 2) in whom the RV free wall was presumably involved, TAPSE was decreased. It is probable that in patients with extensive involvement of both the interventricular septum and RV free wall, TAPSE will be further decreased. The right ventricle has much smaller transverse dimensions as compared to the left ventricle. Although the surface to volume ratio is larger for the right ventricle than for the left, such that small change in transverse dimension will cause a large increase in ejection, it is likely that to achieve normal ejection, most of the change in dimension will have to be in another plane. Our data support this view. Thus, changes in transverse dimensions did not correlate with RVEF while TAPSE did.

Subcostal 2DE. Our study has shown that although adequate tracings of the right ventricle can be made in some patients in the subcostal view, analysis of this view did not correlate well with RVEF. This is probably due to the angle of interrogation applied in this view such that the cross section obtained is not at the level of maximal RV dimensions and is more subject to changes due to cardiac rotation. In a recent report, Starling et al.[18] reported a close correlation between RVEF as measured by radionuclide angiography and subcostal measurement of RV dimensions with the use of 2DE in patients with chronic obstructive lung disease. The difference in results between their report and ours may be explained by the difference in patient populations studied.

TAPSE in coronary artery disease patients. Our method of assessing RVEF by 2DE had close correlation with RVEF as measured by radionuclide angiography, a more standard procedure; according to the linear regression equation 3.2 × TAPSE in mm = RVEF. In our study population, consisting of normal subjects and patients with coronary artery disease, RVEF ranged from 19% to 52%; the TAPSE in our normal population was consistently greater than 15 mm. In the subset of patients with anteroseptal infarctions, whose RVEF was not significantly different from that of normal subjects (47.5 ± 0.7 vs 43.3 ± 2.2), the tricuspid annular plane motion was also consistently greater than 14 mm. In the subgroup of patients with inferior infarctions, whose RVEF was 29.5 ± 3.1, the tricuspid annular plane motion was less than 12.5 mm. In those with RVEF less than 25%, the tricuspid annular plane motion was less than 8.5 mm with one exception. Thus, despite a limited number of patients in our study, this new simple measure (TAPSE) clearly separated normal subjects from patients with reduced RVEF.

Limitations of TAPSE. Our method has some potential limitations. First, it does not take into account the total cardiac motion during systole. As has been shown previously, the apex of the heart is relatively stable during the cardiac cycle. The base of the heart moves anteriorly and caudally during systole at the same time undergoing a slight rotation.[18] Second, exaggerated cardiac motion in patients with pericardial effusion may provide erroneous results. Third, the accuracy of this measurement has been based on close correlation with radionuclide estimates of RVEF. While equilibrium blood pool scanning is currently accepted as generally reliable, its accuracy and reproducibility in a large number of patients remains to be demonstrated.

Conclusions. The advantages of the proposed method in which TAPSE is used to estimate RVEF include simplicity, reproducibility, and absence of geometric assumptions or traceable endocardial outlines. Thus, although more accurate assessments may be made with sophisticated reconstruction approaches utilizing computer assistance,[14-16] present state of the art 2DE does not allow consistent use of these methods in many patients. In summary, a new simple method is described for estimating RVEF from measurement of tricuspid annular motion from end diastole to end systole by means of 2DE. In addition, with the use of standard approaches, the apical four-chamber view reflected RV function more accurately than the subcostal view in normal subjects and patients with coronary artery disease.

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