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Right Ventricular Abnormalities Assessed by Myocardial Single-Photon Emission Computed Tomography Using Technetium-99m Sestamibi/Tetrofosmin in Right Ventricle-Originated Ventricular Tachyarrhythmias

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OBJECTIVES We sought to determine whether right ventricular (RV) perfusion imaging with technetium-99m (Tc-99m) sestamibi or tetrofosmin single-photon emission computed tomography has diagnostic benefit for RV-originated ventricular tachyarrhythmias (RVT).

BACKGROUND Identification of RV abnormalities is clinically important to establish RVT etiology.

METHODS Forty-seven patients with RVT (23 with idiopathic and 24 with organic RVT due to arrhythmogenic RV or dilated cardiomyopathy, cardiac sarcoidosis or myocarditis) were compared to 25 control subjects. Right ventricular uptake score, as assessed by modified tomographic imaging, and regional RV count relative to peak left ventricular (LV) count (RV/LV count ratio) were compared with RV regional and global function.

RESULTS Regional RV uptake score correlated well with the RV/LV count ratio, and segmental abnormality was more frequently ($p = 0.001$) detected in the organic RVT group (22 [92%] of 24 patients) than in the idiopathic RVT group (4 [17%] of 23 patients) or the control group (8 [32%] of 25 patients). The total RV score (8.4 ± 3.8) in the organic RVT group was significantly lower than that in the idiopathic RVT group (15.6 ± 1.6) or the control group (15.1 ± 1.8). The total RV score correlated with RV EF ($r = 0.702$, $p < 0.001$). A total RV score <12 differentiated the organic RVT group from the other two groups, with a sensitivity of 79% and a specificity of 100%. The asynergic RV regions had a significantly lower RV/LV count ratio and RV score as compared with the nonasynergic regions and were identified by RV assessment, with a sensitivity of 76.1% and a specificity of 76.6%.

CONCLUSIONS Right ventricular perfusion tomography using a Tc-99m–labeled tracer is clinically useful for the noninvasive detection of RV myocardial damage in patients with RVT and for differentiating organic from idiopathic RVT. (J Am Coll Cardiol 2000;36:1767–73) © 2000 by the American College of Cardiology

A wide spectrum of pathologic backgrounds, such as arrhythmogenic right ventricular cardiomyopathy (ARVC), sarcoidosis and myocarditis, are thought to possibly be involved in right ventricle (RV)-originated ventricular tachycardia (RVT) (1–11). This ARVC, a progressive "dysplastic" RV disorder possibly leading to cardiac sudden death (1–3), has been noted because of its familial (4–9) and endemic occurrences (10,11). Although myocardial biopsy and contrast right ventriculography can provide clinically important pathognomonic findings, noninvasive methods are more preferable to invasive procedures for an early and reliable diagnosis and identification of high risk individuals among suspected or asymptomatic patients and affected families and for long-term management of patients with ARVC. In contrast, 30% to 50% of RVT cases are idiopathic (12,13), with a better prognosis (12,13). Thus, despite their clinical importance, clinical examinations have not always been useful for a differential diagnosis (2,4,8,9,11,14–16). Although thallium-201 myocardial imaging is an important diagnostic method, it does not have sufficient radioactivity to facilitate visualization of the RV myocardium, except for use in the detection of RV hypertrophy or overload (17–21). Recently established technetium-99m (Tc-99m)-labeled perfusion traces are currently used because they are easily and rapidly prepared, they offer appropriate dosimetry and photopeak activity and a high diagnostic efficacy for detecting coronary artery disease and they might be a potent diagnostic tool for RV perfusion assessment (22–25). However, the data are sparse concerning RV perfusion abnormalities and the clinical implications for patients with RVT, and RV uptake of a Tc-99m–based tracer has not been evaluated with a view to detecting abnormal RV perfusion.

In this study, we sought to determine whether modified RV perfusion tomography with a Tc-99m–labeled tracer is capable of accurate, noninvasive assessment of RV myocar-

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Abbreviations and Acronyms

ARVC = arrhythmogenic right ventricular (dysplastic) cardiomyopathy
ECG = electrocardiogram or electrocardiographic
EF = ejection fraction
LV = left ventricle or ventricular
ROC = receiver operating characteristic
ROI = region of interest
RV = right ventricle or ventricular
RVT = right ventricle-originated ventricular tachyarrhythmia
Tc-99m = technetium-99m
VT = ventricular tachycardia

dial damage in patients with RV cardiomyopathy and of differentiating organic from idiopathic RVT.

METHODS

Subjects. With the written, informed consent of the subjects, and in accordance with the ethical guidelines of our university hospital, 72 subjects were prospectively enrolled in this study. There were 48 males and 24 females (age 45 ± 18 years old [range 9 to 78]); 25 control subjects without ventricular tachycardia (VT) and 47 patients with RVT that had a left bundle branch block QRS complex configuration. On the basis of standard clinical findings, patients with RVT were divided into two groups: 1) 23 patients with RVT without RV dysfunction or structural cardiovascular disease (idiopathic RVT group); and 2) 24 patients with RVT with RV dysfunction due to structural cardiovascular disease (organic RVT group)—12 with ARVC, 5 with cardiac sarcoidosis, 4 with idiopathic dilated cardiomyopathy, 2 with myocarditis and 1 with familial atrioventricular block (Table 1). All 25 control subjects had just paroxysmal supraventricular tachycardias, but there was no evidence of ventricular tachyarrhythmias or organic heart disease on physical examination, chest radiograph, electrocardiogram (ECG) or echocardiogram.

The diagnosis of ARVC was established according to task force criteria (11): 1) ECG and RV wall motion abnormalities (n = 12, 100%); 2) familial occurrences of VT or sudden cardiac death (n = 6, 50%); 3) prolongation of the QRS complex duration (epsilon wave) in the right precordial leads (V_1–V_3) or positive late potentials, or both (n = 11, 92%); and 4) abnormal repolarization (T-wave inversion) in precordial leads V_1–V_3 (n = 7, 64%). Right ventricular biopsy specimens revealed myocardial fatty degeneration in nine patients with ARVC, and the mean total ARVC task force score in 12 patients with ARVC was 7.3 ± 1.7 (range 4 to 10). Idiopathic RVT was diagnosed when no pathognomonic signs other than ventricular tachyarrhythmias were demonstrated on the 12-lead ECG or by Holter monitoring, or both. There was no abnormality on the signal-averaged ECG or treadmill exercise test, no ventricular wall motion on the transesophageal echocardiogram or contrast right ventriculogram, and no familial history of cardiac disease, ventricular tachyarrhythmias or sudden death in the 23 patients with idiopathic RVT.

Characteristics of tachyarrhythmias. All 47 patients with RVT had an arrhythmia history of more than three months,

Table 1. Clinical Background of Study Subjects

	Control Group (n = 25)	Idiopathic RVT Group (n = 23)	Organic RVT Group (n = 24)
Age (yrs)	50 ± 16	39 ± 21	47 ± 20
Male/female	16/9	13/10	19/5
Etiologic bases (n)			
ARVC	0	0	12 (50%)
Cardiomyopathy	0	0	4 (17%)
Sarcoidosis	0	0	5 (21%)
Myocarditis	0	0	2 (8%)
Familial AV block	0	0	1 (4%)
Clinically documented ventricular arrhythmias			
Sustained RVT (%)	0	7 (30%)	16 (67%)*
Nonsustained RVT (%)	0	8 (35%)	3 (13%)
Frequent PVCs (%)	0	8 (35%)	5 (21%)
VF (%)	0	0 (0%)	1 (4%)
Antiarrhythmic medications			
Class I			
a	0	5 (22%)	9 (38%)
b	0	4 (17%)	5 (21%)
c	0	1 (4%)	5 (21%)
Class II	0	5 (22%)	12 (50%)*
Class III	0	1 (4%)	0 (0%)
Class IV	0	4 (17%)	5 (21%)

*$p < 0.05$ versus control or idiopathic RVT group. Data are expressed as the mean value ± SD or number (%) of patients.
ARVC = arrhythmogenic right ventricular cardiomyopathy; AV = atrioventricular; RVT = right ventricle-originated ventricular tachycardia; PVC = premature ventricular contraction; VF = ventricular fibrillation.

spontaneous VT and frequent premature ventricular contractions, all of which showed a wide (>0.14 s) left bundle branch block appearance. In particular, all idiopathic RVTs had an inferior axis and a typical left bundle branch block QRS complex appearance. The clinical backgrounds and types of VTs showed no significant differences between the idiopathic and organic RVT groups, except for background cardiac disorders and the use of class II anti-arrhythmia agents (Table 1). Electrophysiologic studies were performed in 35 patients with RVT for catheter ablation therapy, and RV outflow tract origins were established in 16 patients with idiopathic RVT (70%) and 19 patients with organic RVT (79%).

Scintigraphic evaluation. IMAGING PROTOCOL. Technetium-99m–labeled sestamibi (600 MBq, n = 26) or tetrofosmin (592 MBq, n = 46) was injected intravenously at rest. Thirty or 60 min later, tomographic data were acquired at 6°; increments for 40 s per increment during a 360° rotation using a three-headed gamma camera (Toshiba GCA-9300A/DI, Tokyo, Japan) with a high resolution, parallel-hole collimator and were stored in a 64 × 64 word matrix nuclear medicine computer system. The photon energy limit was set at a 20% window around the 140 keV photon peak of Tc-99m. After reconstruction using a filtered back-projection algorithm with a Ramp filter, short-axis, vertical and horizontal long-axis tomograms were obtained. Receiver-operating characteristic (ROC) curve analysis was performed to determine the optimal cut-off value for visualization of the RV wall and for the semiquantitative assessment as follows: RV tomograms were obtained with 5%-graded upper cut-off levels from 25% to 75% of the peak intensity of control LV regions in 10 control subjects and in 10 patients with ARVC with a diffuse RV aneurysm, and then a ROC curve was created and 50% was identified as the optimal upper cut-off value for RV wall visualization in this study.

IMAGE ANALYSIS. The RV wall was divided into six segments on two short-axis tomograms at the basal and apical levels and one horizontal long-axis image at the mid-ventricular level. The two short-axis slices were selected from the basal and apical sites, which were located approximately at the one-third and two-third positions from the apex; in particular, a nonmyocardial region around the RV outflow tract was carefully avoided (Fig. 1). All tomographic images were evaluated separately by two experienced nuclear cardiologists (E.M. and K.T.) who had no knowledge of the diagnostic and arrhythmia data. When results between the two examiners were inconsistent, the final score was determined by the consensus. Eighty-seven percent of the results were consistent, and 98% were within a 1-score difference. Myocardial uptake in the six RV segments was graded with a 4-point scoring system: 3+ = normal; 2+ = slightly reduced uptake; 1+ = markedly reduced uptake; and 0 = complete defect. Right ventricular uptake was also assessed by a total RV score that was calculated by the summation of scores in the six RV segments.

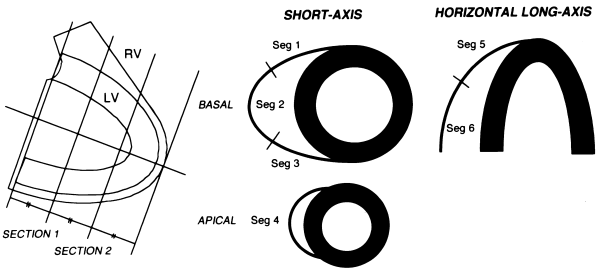

Figure 1. Selection of two short-axis tomograms and one horizontal long-axis tomogram for RV assessment and schematic presentation of six RV segments (Seg). Segments 1, 2, 3 and 4 are derived from the basal and apical one-third slices, in which the whole LV circumference is visualized. The RV horizontal long axis (segments 5 and 6) is selected at the mid-ventricular transverse level by reference to LV slices. Right ventricular uptake was visually scored as follows: 3+ = no definite abnormality; 2+ = slight reduced uptake; 1+ = markedly reduced uptake; 0 = defect.

ASSESSMENT OF RIGHT TO LEFT VENTRICULAR COUNT RATIO. The right to left ventricular (RV/LV) count ratio was quantitatively assessed. On the same short-axis and horizontal long-axis tomograms as used for visual semiquantitative assessment, a square region of interest (ROI) on 2 × 2 pixel was manually and carefully positioned to measure myocardial activity by referring to RV uptake scores. An LV area with the greatest brightness (uptake) on a standard LV tomogram was selected as a control region for LV count measurement, and the ROI was also placed over this area, giving the maximal counts per pixel. The mean count of each region was calculated, and the RV/LV count ratio was obtained in 62 subjects by using the following equation: RV/LV count ratio = mean RV count/mean LV count.

CARDIAC FUNCTION ASSESSMENT. Radionuclide ventriculography was performed at rest using an intravenous injection of Tc-99m–labeled human serum albumin (740 MBq) to assess LV and RV ejection fractions (EFs). Data were acquired in an ECG-gated mode of 500 cardiac cycles from a left anterior oblique view, using a large-field-of-view gamma camera (Shimadzu SNC 5100R, Tokyo, Japan) and a low energy, general-purpose, parallel-hole collimator after the radioactivity had equilibrated. Right ventricular wall motion was evaluated by contrast cine right ventriculography in 16 patients with organic RVT and in 6 patients with idiopathic RVT and was compared with scintigraphic data. The positional relation between the angiographic regions and six scintigraphic segments was defined as follows: the RV inflow region corresponded to segments 3 and 6; the RV apex to segments 4 and 5; the RV lateral wall to segment 2; and the RV outflow to segment 1. Definite akinesia or aneurysm formation, or both, was defined in this study as ventriculographic asynergy. However, segment 2 (RV lateral wall) was deleted from the wall motion analysis because of the difficulty in wall motion assessment by contrast right ventriculography in this region. Right ventriculography was performed using a standard technique from two projections

(anteroposterior and lateral views), and the data were evaluated by two cardiologists using a cine mode of display of contrast ventriculograms.

Statistical analysis. All data were expressed as the mean value ± SD, and comparison of variables between two groups was analyzed by using the nonpaired Student *t* test. The incidence analyses were subjected to the chi-square test. Numeric variables of more than two subgroups were first indicated by one-way analysis of variance. If the difference was found to be sufficient, the *t* test with Bonferroni correction was performed. The correlation between two independent variables was examined by a single linear regression test. A p value < 0.05 was considered to be statistically significant.

RESULTS

Case demonstration. Figures 2 and 3 demonstrate the representative tomographic images of patients with organic RVT and idiopathic RVT and control subjects. Although the LV wall was identified in white owing to the image modification with the upper cut-off level of 50%, the whole RV wall was normally delineated in the patients with idiopathic RVT and control subjects (Fig. 2). In contrast, three patients with ARVC (Fig. 3) had profound multiple defects with cavity dilation in the RVs.

Scintigraphic RV abnormality. The organic RVT group had significantly lower RV scores in all segments as compared with the control and idiopathic RVT groups (Table 2). A severe abnormality (RV scores 0 and 1) was observed more frequently in the organic RVT group (22 [92%] of 24 patients) than in the idiopathic RVT group (4 [17%] of 23 patients, $p = 0.001$) or the control group (8 [32%] of 25 patients, $p = 0.001$) (Table 2). The overall incidence of severe abnormalities in the organic RVT group was greater than that in the idiopathic RVT group or control group (78 [54%] of 144 segments vs. 4 [3%] of 138 segments vs. 11 [7%] of 150 segments, respectively, $p < 0.05$). Multiple defects detected in three or more segments were observed in 15 patients with organic RVT (63%), but not in any of the patients with idiopathic RVT or control subjects ($p = 0.0001$).

Comparison between RV function and scintigraphic variables. The total RV score in the organic RVT group (8.4 ± 3.8) was significantly lower than that in the idiopathic RVT group (15.6 ± 1.6, $p < 0.0001$) or control group (15.1 ± 1.8, $p < 0.0001$) (Fig. 4). When the total RV score of ≤11 was used to differentiate patients with organic RVT from other subjects, the sensitivity, specificity and diagnostic accuracy were 79% (19 of 24 patients), 100% (48 of 48) and 93% (67 of 72), respectively. The total RV score had a significant positive correlation with RVEF: $y = 1.4x + 23.7$, $r = 0.702$, $n = 45$, $p < 0.001$) (Fig. 4). The total RV score also correlated significantly with RVEF when only the 24 patients with organic RVT were considered ($y = 1.6x + 22.8$, $r = 0.580$, $p < 0.01$).

Right ventricular asynergy was more frequently observed ($p < 0.05$) in the organic RVT group than in the idiopathic RVT group (Table 2). The RV/LV count ratio had a significant positive correlation with RV score (Fig. 5A). In the 22 patients with RVT who underwent contrast RV angiography (Fig. 5B), asynergic segments had significantly ($p < 0.05$) smaller RV scores and RV/LV count ratios as compared with nonasynergic segments. The overall sensitivities and specificities in the detection of asynergy/aneurysm were 76.1% (35 of 46 segments) and 76.6% (49 of 64) for the use of the lower RV scores 0 and 1, and 67.4% (31 of 46 segments) and 81.3% (52 of 64) for the use of the RV/LV count ratio <0.3, which is the mean value − 2 SD in segments with a normal score of 3 (Fig. 5).

DISCUSSION

Our results revealed that a simple modification of tomographic imaging with Tc-99m–based tracers for RV assessment can contribute to the identification of high risk, individuals with RVT, 1) because Tc-99m tracer RV

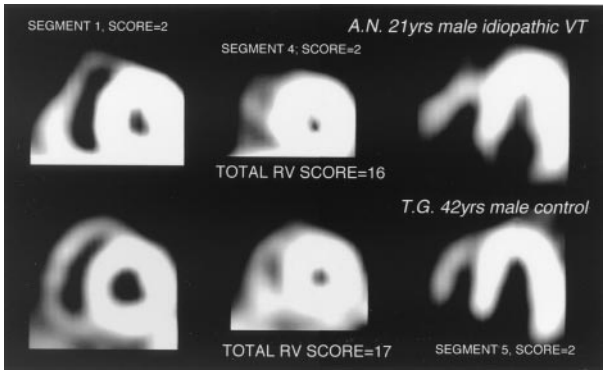

Figure 2. Right ventricular tomograms derived from a patient with idiopathic RVT **(upper panel)** and a control subject **(lower panel)** show neither definite abnormality nor RV dilation.

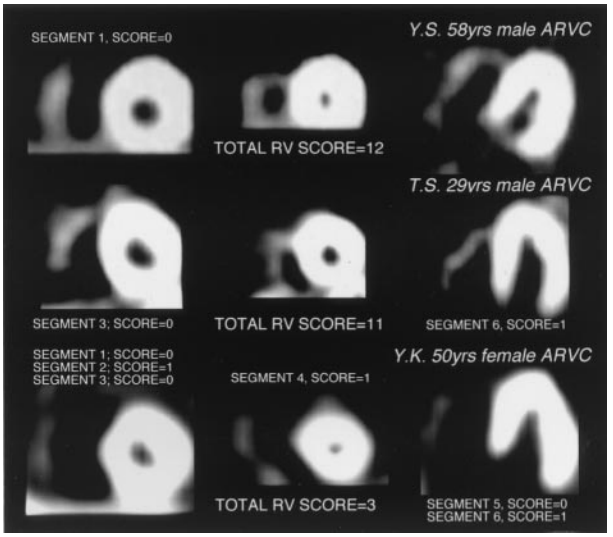

Figure 3. Three typical RV abnormalities observed in the outflow **(top)**, inflow **(middle)** and multiple regions **(bottom)** in patients with ARVC.

Table 2. Scintigraphic and Right Ventriculographic Data of Study Subjects

	Control Group (n = 25)	Idiopathic RVT Group (n = 23)	Organic RVT Group (n = 24)
Right ventricular perfusion SPECT			
Right ventricular perfusion score			
Segment 1	2.2 ± 0.5	2.3 ± 0.7	1.0 ± 0.8*†
Segment 2	2.8 ± 0.4	2.9 ± 0.3	1.9 ± 0.5*†
Segment 3	2.2 ± 0.9	2.4 ± 0.8	1.2 ± 1.0*†
Segment 4	2.5 ± 0.5	2.5 ± 0.5	1.1 ± 0.8*†
Segment 5	2.6 ± 0.7	2.7 ± 0.6	1.2 ± 1.0*†
Segment 6	2.8 ± 0.4	2.8 ± 0.4	2.0 ± 0.8*†
Prevalence of lower perfusion uptake score with SPECT less than 2			
Subjects	8/25 (32%)	4/23 (17%)	22/24 (92%)*†
Segments	11/150 (7%)	4/138 (3%)	78/144 (54%)*†
Prevalence of multiple-perfusion abnormality‡			
Subject	0/25 (0%)	0/23 (0%)	15/24 (63%)*†
Radionuclide ventriculography	(n = 9)	(n = 15)	(n = 21)
Ejection fraction (%)			
Right ventricle	48 ± 8	44 ± 8	34 ± 10*†
Left ventricle	55 ± 7	53 ± 9	48 ± 10
Right ventriculographic wall motion abnormality			
		(n = 6)	(n = 16)
Inflow		0 (0%)	4 (25%)
Apex		0 (0%)	13 (81%)†
Outflow		0 (0%)	9 (56%)†

*$p < 0.05$ versus control group. †$p < 0.05$ versus idiopathic RVT group. ‡Multiple-perfusion abnormality was defined when there were three or more abnormal segments. Data are expressed as the mean value ± SD or number (%) of patients or control subjects.

RVT = right ventricle-originated ventricular tachyarrhythmia; SPECT = single-photon emission computed tomography.

myocardial imaging facilitates RV visualization in any clinical condition; 2) because of fewer dead angles for RV assessment as compared with two-dimensional echocardiography or contrast RV angiography; and 3) because semiquantitative and quantitative assessments of the RV wall using multiple slices are feasible.

Right ventricular myocardial damage in patients with RVT. Although RV wall motion abnormality is one of the major criteria for RV assessment, along with histologic

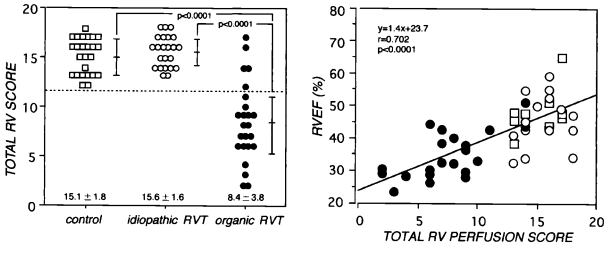

Figure 4. Comparison of total RV scores among the three groups and the correlation with RVEF. If the cut-off value of the total RV score of ≤11 is used for differentiating patients with organic RVT from those with idiopathic RVT or normal subjects, the sensitivity, specificity and diagnostic accuracy were 79% (19 of 24 patients), 100% (48 of 48) and 93% (67 of 72), respectively. The organic RVT group had a significantly lower total RV score as compared with the control and idiopathic RVT groups **(left panel)**. The total RV score had a close positive correlation with RVEF derived from radionuclide ventriculography: RVEF (%) = 1.4× total RV score + 23.7 ($r = 0.702$, $p < 0.001$) **(right panel)**.

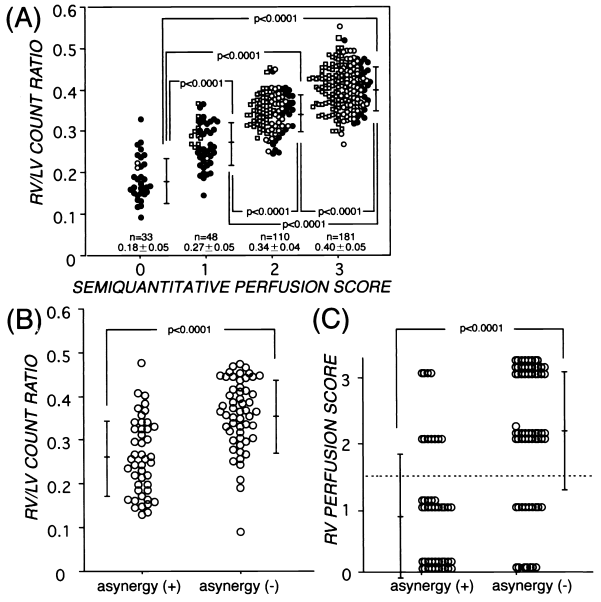

Figure 5. A, There was a close correlation between the RV/LV count ratio and RV visual score. Note that there were significant differences in the RV/LV count ratio among RV scores. There were significant differences in the RV/LV count ratio **(B)** and in RV score **(C)** between segments with and those without RV asynergy. The overall sensitivity and specificity of scintigraphic determination by using the lower scores 0 and 1 for detecting RV asynergy were 76.1% (35 of 46 segments) and 76.6% (49 of 64), respectively **(C)**. The **solid circles, open circles** and **open squares** indicate organic RVT, idiopathic RVT and control subjects, respectively.

changes and familial history (11), conventional methods such as contrast right ventriculography and two-dimensional echocardiography have substantial limitations for this purpose, owing to their invasiveness, anatomic limitations, which hinder precise visualization of the RV segments, and difficulties in appropriate image analysis. Transesophageal echocardiography and magnetic resonance imaging are likely to be promising alternatives (14,15). However, the morphologic complexity of the RV and the wide spectrum of myocardial involvement from mild, focal to severe, multiple lesions in RVT (1–11,16) make the anatomic and functional evaluations of the RV difficult in routine clinical practice. The present results demonstrated that RV abnormalities identified by modified tomographic imaging are closely related to organic RV damage, leading to focal and global RV dysfunction. Therefore, the following tomographic findings are likely to be useful for differentiating organic RVT from idiopathic RVT with a high diagnostic accuracy: 1) a more profound reduction of tracer uptake (score 0 or 1); 2) multiple defects observed in three or more RV segments; 3) reduced total RV score <12; and 4) an RV/LV count ratio <0.3. The close correlations of scintigraphic RV variables with RV regional wall motion abnormality and EF also lend support to the methodologic rationale of the present technique for RV assessment in patients with RVT.

The six-segmentation of the RV in this study was designed to correspond to "dysplasia triangles," which are susceptible to ARVC-related myocardial damage (2). Fifteen of 288 segments in eight control subjects and four patients with idiopathic RVT showed lower RV scores. However, consistent with echocardiographic and RV angiographic findings, the impaired RV uptake was not related to clinical, structural or functional abnormalities. Our patients with idiopathic RVT had identical RV variables as compared with control subjects. Therefore, the mild RV abnormality in control subjects and patients with idiopathic RVT seems to be artifactual or due to physiologic variations in these subjects. Using cine magnetic resonance imaging, Carlson et al. (15) observed RV structural and functional abnormalities, localized at an RV outflow tract more often in patients with "idiopathic" RV outflow tract VT (95%) than in control subjects (12.5%) or other cardiac patients (39%). Although it is not clear whether radioisotope RV imaging underestimates RV abnormalities localized at an RV outflow tract in patients with idiopathic RVT, there may be several explanations for the discrepant results. The idiopathic RVT population may be heterogeneous in terms of their arrhythmia origins and etiologies; the spatial resolution of magnetic resonance imaging is superior to that of radioisotope RV imaging. In this study, an upper RV outflow tract located above the upper one-third RV level was not evaluated because fewer cardiac muscle fibers at the RV outflow tract close to a pulmonary artery possibly lead to an artifactual RV perfusion abnormality. Finally, RV wall motion and thickness could not be appreciated by non-gating RV tomographic imaging in this study. Unlike cine magnetic resonance imaging, however, the present findings revealed that a loss of myocardial tissue is highly involved in organic RVT manifestation and that the multiple patchy RV defects are less unusual and likely to be responsible for RV functional abnormalities in patients with organic RVT.

Scintigraphic visualization of RV by modified perfusion tomography. Right ventricular perfusion imaging with the simple image modification used here has several advantages—namely, easier approach, noninvasiveness and precise identification of RV morphology and localization of abnormalities (22–25). Although the RV wall can be visualized by this technique, even in patients without RV hypertrophy, overload or congenital anomaly (19,22–25), there were no available data on the RV perfusion state in healthy subjects assessed by this technique and we extended the possibility of its application to patients with RVT. In addition, quantitative techniques attempted by other investigators (22–24) appear to be complicated in clinical practice. The present study used the cut-off value of 50% of peak LV activity to delineate the RV wall by isotope imaging based on ROC curve analysis. However, because the value depends on a maximal LV count, both the imaging protocol and tracer dosage could influence the image equality and optimal cut-off value for RV visualization by perfusion imaging. Furthermore, RV uptake on modified tomographic imaging was evaluated by using a standard, semiquantitative scoring system and quantitatively by calculating the RV/LV count ratio. Both results are likely to be identical, supporting the potential of the image analysis presented here for RV assessment, although there were overlapping RV/LV count ratios among visual scores. Therefore, if LV perfusion is diffusely reduced, which occurs in some patients with ARVC with LV involvement (16,26), RV uptake and the RV/LV count ratio may be overestimated. Nevertheless, the present results demonstrated that visual scintigraphic assessment using the 4-point scoring system can contribute to the detection of RV asynergy and to the identification of organic RV injury in patients with RVT.

Study limitations. Although this study used both semiquantitative and quantitative methods for RV assessment, there are several technical limitations. Tremendous activities of Tc-based tracers in the liver or gallbladder, or both, may make the RV inferior wall assessment difficult because of radioactive scattering and artifactual appearance. In this study, tomographic imaging started $\geq$30 min after the tracer injection; therefore, substantial artifacts were eliminated. The efficacies of echocardiography and contrast right ventriculography are unlikely to be established as tools for the precise evaluation of focal RV abnormalities, because of the anatomic complexity of the RV and because of their technical limitations (15). Patients with an established diagnosis of idiopathic or organic RVT were entered into the present study, meaning that it is still undetermined whether the present technique can be applied to screening

or early detection of RV lesions in asymptomatic pedigree members of the RVT or ARVC patient group. A large-scale, prospective study using patients with RVT and their family members is necessary to establish the clinical efficacy of the present method. Finally, it is difficult to precisely correlate scintigraphically identified RV abnormalities with other results, including those of electrophysiologic RVT origins, because of limitations in spatial resolution and the difficulty in registering lesions.

Although etiologies of patients with idiopathic RVT are not necessarily revealed, the present study strongly suggests that the etiology of scintigraphic RV abnormalities originates in arrhythmogenicity or a substrate of RVT, and that some patients with idiopathic RVT have subclinical RV myocardial damage or disorders (15) that may manifest themselves during further follow-up.

Conclusions. Right ventricular tomographic imaging with a technetium-99m tracer by a simple cut-off modification can contribute to the noninvasive identification of RV myocardial damage in patients with RVT and to the clarification of the pathophysiologic backgrounds.

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