Right ventricular pressure-volume loops using simultaneous radionuclide angiography with a multiwire gamma camera and right heart catheterization

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Background. **The purpose of this study was to generate right ventricular (RV) pressure-volume loops (PVLs) from time-activity curves obtained by first-pass radionuclide angiography (RNA) and RV pressures obtained by right heart catheterization.**

Methods and Results. **Short-lived tantalum 178 was used to obtain first-pass RNA at baseline (n = 31), after nitroglycerin (n = 5), or after the conclusion of cardiac catheterization (n = 13). From the radionuclide-derived RV ejection fraction and thermodilution stroke volume, the RV end-diastolic volume and end-systolic volume were measured. Special proprietary software was developed and used to integrate the pressure and the RNA data. The mean heart rate was 80 ± 17 beats/min; RV ejection fraction, 39% ± 12%; RV end-diastolic volume, 217 ± 79 mL; RV end-systolic volume, 142 ± 74 mL; and RV end-diastolic pressure, 10 ± 7 mm Hg. The RV PVLs were of high quality and reproducible.**

Conclusions. **This study provides proof of concept of the feasibility of generating RV PVL; the short half-life (10 minutes) and low energy (59 keV) of Ta-178 allow the generation of multiple loops at low radiation exposure. Such studies could be performed at the bedside and provide a wealth of information that may have clinical and research merits. (J Nucl Cardiol 2005;12:435-40.)**

Key Words: Right ventricular function • pressure-volume loop • heart failure • radionuclide angiography • cardiac catheterization

Detailed assessment of right ventricular (RV) function is often more difficult than assessment of left ventricular (LV) function because of the complex geometry of the RV chamber, which makes volumetric analysis cumbersome and less accurate with virtually all imaging modalities.[1] With the increasing interest in RV function in the outcome of patients with heart failure, pulmonary hypertension, and a variety of other cardiac disorders,[2-8] a more precise measurement would be of considerable interest. The generation of LV pressure-volume loops (PVLs) has provided a powerful tool to assess not only the contractile performance but also diastolic function.[9,10] The generation of such PVLs has been attempted previously with contrast right ventriculography and the use of conductance catheters[11-15] and, more recently, with combined magnetic resonance imaging and pressure measurements.[16]

The purpose of this pilot study was to investigate the feasibility and reproducibility of generating RV PVLs by use of simultaneous radionuclide angiography (RNA) and right heart catheterization. RNA provides the input function of the time-activity curve proportional to the volume-time curve, and right heart catheterization provides the input function for the RV pressure data. Special proprietary software was developed by Proportional Technologies, Inc (Houston, Tex) to integrate these two sets of data.

MATERIAL AND METHODS

We studied 31 patients (22 men and 9 women), aged 59 ± 14 years, who were referred for diagnostic cardiac catheterization for clinical indications (chest pain syndromes presumed to be due to coronary artery disease and/or heart failure). Patients with moderate to severe

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Table 1. Pertinent data at baseline in 25 patients

	HR (beats/min)	CO (L/min)	RV SP (mean) (mm Hg)	RV EDP (mm Hg)	LV EF (%)	RV EF (%)	RV EDV (mL)	RV ESV (mL)
Patient No.								
1	69	4.6	88	4	15	36	188	120
2	100	5.8	54	15	52	47	124	66
3	109	9.4	52	13	87	43	200	114
4	66	4.3	56	27	76	45	144	80
5	82	8.0	42	9	66	50	194	97
6	66	4.1	31	4	59	52	112	54
7	69	7.2	41	5	79	34	311	241
8	70	6.9	24	8	28	43	224	127
9	100	8.0	43	5	79	60	133	54
10	71	5.4	55	5	15	21	361	284
11	77	4.0	27	4	63	23	222	170
12	80	8.1	41	8	46	34	294	193
13	80	4.4	30	10	55	40	135	80
14	120	6.5	31	8	64	29	187	133
15	77	4.6	54	19	32	21	283	224
16	92	7.7	60	18	32	22	388	304
17	69	6.6	39	5	53	49	196	100
18	104	5.4	74	26	20	20	255	204
19	61	5.1	36	2	73	39	210	128
20	77	4.3	35	12	17	24	235	179
21	59	3.3	91	12	76	40	140	84
22	62	5.7	45	9	58	52	180	87
23	72	9.1	66	11	35	34	370	246
24	109	7.3	35	5	60	50	133	66
25	68	6.4	51	8	77	46	203	109
Mean ± SD	80 ± 17	6.1 ± 1.7	48 ± 18	10 ± 7	53 ± 23	39 ± 12	217 ± 79	142 ± 74

HR, Heart rate; *CO,* cardiac output; *SP,* systolic pressure; *EDP,* end-diastolic pressure; *EDV,* end-diastolic volume; *ESV,* end-systolic volume.

valvular regurgitation, atrial fibrillation, multiple premature beats, unstable angina, acute myocardial infarction, or pulmonary edema were excluded. All patients signed a consent form approved by the institutional review board, and there were no complications related to the study.

The mobile multiwire gamma camera was positioned in the cardiac catheterization laboratory adjacent to the patient, and the radioactivity was eluted on site from the generator housed within the camera chassis. The camera detector was positioned just above the patient's chest. Because the camera detector has a range of elevation to 56 inches and the horizontal arm can extend 36 inches, acquisition of first-pass RNA studies can be easily accomplished in this setting. The 3 electrocardiographic leads attached to the unit were placed on the patient's right arm, left arm, and right leg for gating of RNA studies and recording of heart rate.

All patients underwent right and left heart catheterization and coronary angiography. The cardiac output was measured with the thermodilution method in triplicate. The right heart catheter was positioned in the RV chamber during acquisition of RNA imaging, and the pressure signal was fed into the camera system. The RV time-activity curve was generated by first-pass RNA by a bolus injection of 15 to 30 mCi tantalum 178 into the central circulation. To deliver a bolus injection, Ta-178 was delivered into a 3-mL syringe from the tungsten-178/Ta-178 generator. Dose measurement was accomplished via a computer-controlled calibrator. Ta-178 was then loaded into an external line connected to the atrial catheter port. Immediately after depression of a foot pedal of the mobile unit, which signaled the start of data acquisition, Ta-178 was flushed in as a tight bolus with 5 mL of room-temperature saline solution. The first-pass RNA imaging and acquisition of pressure data were continued for 30 seconds at a framing rate of 120 frames per second and a pressure/electrocardiographic data rate of 120 samples per second.[17] Immediately before the

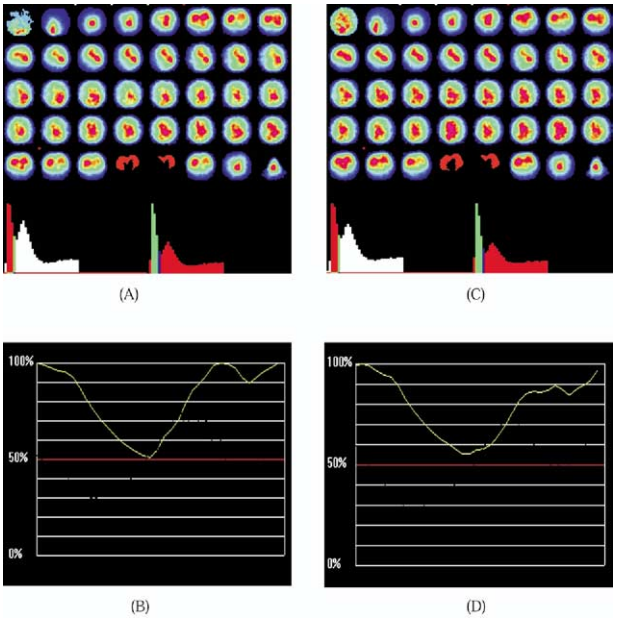

Figure 1. Typical first-pass radionuclide angiogram and pulmonary artery pressure tracing. Images show the transit of the bolus of Ta-178 through the central circulation. Duplicate studies in the same patient (patient 17) are shown. **A**, End-diastolic images acquired from the first study. **B**, Corresponding time-activity curve of RV representative cycle. **C** and **D**, Images and time-activity curve from the second study.

RNA acquisition, the cardiac output was recorded. The baseline study was always obtained before any contrast material was used. To test the reproducibility, we repeated the RNA studies at least twice in 14 patients; each set of studies included complete RNA imaging, RV pressure, and thermodilution cardiac output information. In 5 patients the studies were also repeated after sublingual nitroglycerin administration to cause at least a 10–mm Hg decrease in systolic blood pressure. Finally, in 13 patients the studies were again repeated after the conclusion of contrast angiography.

From the RNA-derived RV ejection fraction (EF) and thermodilution-derived stroke volume, the RV end-diastolic volume and RV end-systolic volume were derived. RNA obviously also provides LV EF measurements. Special analytic software (Proportional Technologies, Inc) was used to integrate the pressure and RNA measurements and to construct the RV PVLs.[18]

Statistical Analysis

Continuous variables are presented as mean ± SD and analyzed by paired *t* test, whereas discrete variables are presented as percentages and analyzed by χ^2 test and Fisher exact test. $P < .05$ was considered statistically significant.

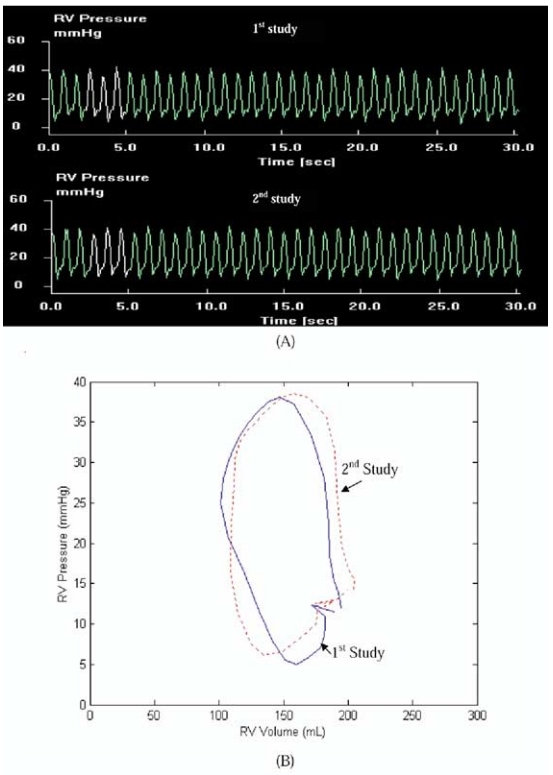

Figure 2. Pressure data and PVLs from the same patient as in Figure 1. **A**, RV pressure tracing of 30-second acquisition time. Note that the pressure segment corresponding to the selected RV phase is highlighted in *white*. **B**, RV PVLs from the first and second study.

RESULTS

The data for 25 patients are shown in Table 1. The data for 6 patients either were incomplete or had technical problems. There were 18 men and 7 women, aged 58 ± 16 years. The patients had heart failure symptoms (New York Heart Association class I-III) resulting from either systolic LV dysfunction (n = 9) or diastolic LV dysfunction (n = 16). Most patients were receiving one or more of the following treatments: β-blocking agents, calcium channel blockers, angiotensin-converting enzyme inhibitors, diuretics, lipid-lowering agents, hypoglycemic agents, and aspirin. None of the patients complained of angina or developed ST-segment shifts during the RNA studies.

Representative examples of first-pass RNA, pressure data, and RV PVLs are shown in Figures 1 through 5. The individual data in the 25 patients are listed in Table 1, the data in the patients with 2 sequential studies are shown in Table 2, the data before and after nitroglycerin are shown in Table 3, and the data at baseline and after contrast angiography are shown in Table 4. Measurements were reproducible. There were no significant

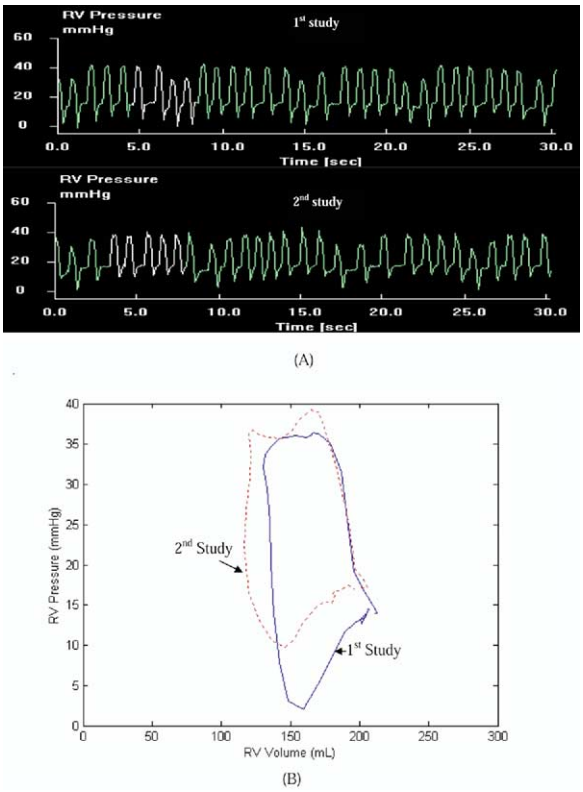

Figure 3. Pressure data and consequent PVLs from another patient (patient 19), showing respiratory effect on pressure and PVLs. **A**, RV pressure tracing of 30-second acquisition time. Note that a selected pressure segment from the first study was acquired during the patient's inspiration (resulting in reduced end-diastolic RV pressure). **B**, RV PVLs from the first and second study. The downward shift of the first study is a result of selected beats falling in the inspiration part of the respiratory cycle.

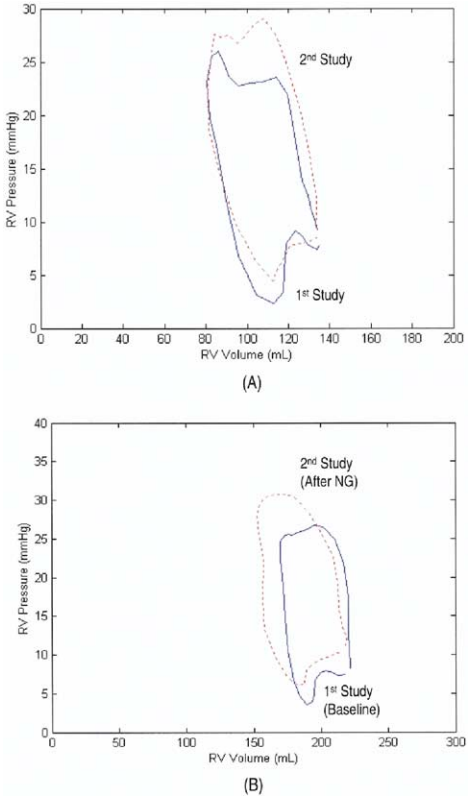

Figure 4. RV PVLs from a patient (patient 13) with duplicate studies at baseline (**A**) and from another patient (patient 11) at baseline and after nitroglycerin (*NG*) (**B**). There is a leftward shift in the loop after nitroglycerin.

changes after nitroglycerin or after contrast angiography, although there was a leftward shift in PVL after nitroglycerin in 1 patient.

DISCUSSION

The complex RV geometry makes precise quantification of RV function much more difficult.[1] Various imaging modalities have been used to study RV function, and these methods (2-dimensional echocardiography, magnetic resonance imaging, and RNA) continue to improve and to provide 3-dimensional information.[19-22] The interest in more precise methods for RV assessment has been generated by a plethora of data demonstrating the importance of RV function in the outcome of patients with heart failure, acute myocardial infarction, pulmonary hypertension, congenital heart diseases, and other cardiac and cardiopulmonary disorders.[2-8,16]

The generation of LV PVLs has proved to be useful to the study of LV contractile and diastolic functions.[9,10] The tedious contrast angiographic method has given way to the use of conductance catheter technology, which makes it possible to have serial studies without the negative inotropic effect of contrast material.[12-16] This method could also be used for RV assessment.[22,23] A hybrid method using first-pass RNA and pressure measurements was also described for LV PVLs with the use of technetium 99m pertechnetate and a multicrystal gamma camera. The use of Tc-99m tracers, however, limits the number of studies because of their long half-life and radiation exposure.[9-11]

The method described here circumvents these problems, as the tracer is ultra–short-lived, is eluted on site, has low radiation exposure, and is optimally imaged by the specially designed mobile gamma camera, which has a high counting efficiency.[23,24] The RV time-activity curve is independent of geometry, and the absolute RV volume is based on 2 geometrically independent methods (thermodilution stroke volume and RNA EF). The volume measurement therefore surpasses other currently

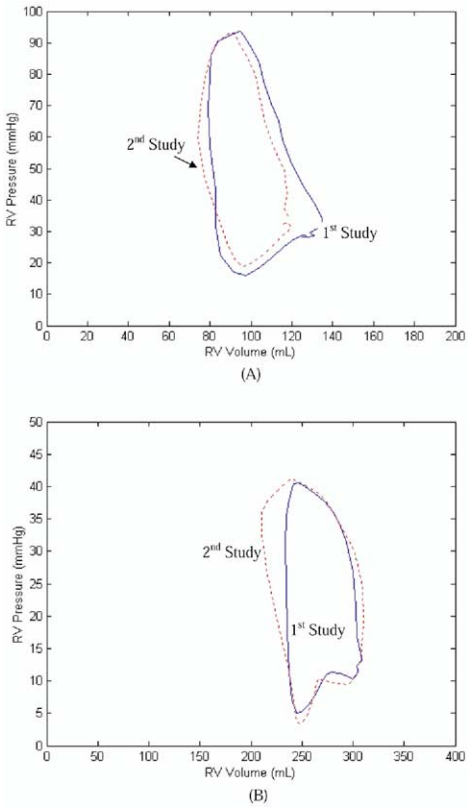

Figure 5. RV PVLs from 2 patients showing abnormal pressure or volume. **A**, RV PVLs show very high systolic pressure (patient 21). **B**, PVLs show large RV volume (patient 7). Studies in each patient were both performed at baseline.

Table 2. Reproducibility of data in 13 patients

Variable	First set	Second set	*P* value
HR (beats/min)	82 ± 15	81 ± 13	.90
RV SP (mm Hg)	51 ± 17	52 ± 18	.84
RV EDP (mm Hg)	11 ± 7	12 ± 9	.64
LV EF (%)	47 ± 23	46 ± 23	.93
RV EF (%)	37 ± 12	38 ± 12	.87
RV ESV (mL)	150 ± 83	144 ± 81	.85
RV EDV (mL)	227 ± 86	221 ± 86	.86

HR, Heart rate; *SP,* systolic pressure; *EDP,* end-diastolic pressure; *ESV,* end-diastolic volume; *EDV,* end-diastolic volume.

available methods. The special software allowed integration of the pressure and radionuclide data and the generation of high-quality PVLs that closely resemble LV PVLs. Validation of the method is necessary in a larger study and especially in populations with failing right ventricles. If confirmed, the method may prove useful in assessing load-independent parameters of RV

Table 3. Data before and after nitroglycerin intervention

Variable	Baseline	Nitroglycerin	*P* value
HR (beats/min)	73 ± 17	76 ± 15	.75
CO (L/min)	5.4 ± 1.9	5.7 ± 1.8	.75
RV SP (mm Hg)	50 ± 25	51 ± 24	.91
RV EDP (mm Hg)	6 ± 4	10 ± 5	.23
LV EF (%)	74 ± 6	73 ± 3	.95
RV EF (%)	42 ± 13	45 ± 14	.72
RV ESV (mL)	109 ± 44	97 ± 41	.68
RV EDV (mL)	182 ± 42	173 ± 45	.77

HR, Heart rate; *CO,* cardiac output; *SP,* systolic pressure; *EDP,* end-diastolic pressure; *ESV,* end-diastolic volume; *EDV,* end-diastolic volume.

Table 4. Data before and after contrast load in 16 patients

Variable	First set	Second set	*P* value
HR (beats/min)	81 ± 16	81 ± 13	.94
CO (L/min)	6.0 ± 1.8	6.1 ± 1.8	.85
RV SP (mm Hg)	50 ± 20	54 ± 20	.64
RV EDP (mm Hg)	10 ± 7	12 ± 9	.40
LV EF (%)	55 ± 22	55 ± 22	.93
RV EF (%)	39 ± 12	40 ± 12	.75
RV ESV (mL)	132 ± 70	124 ± 67	.77
RV EDV (mL)	206 ± 73	200 ± 73	.81

HR, Heart rate; *CO,* cardiac output; *SP,* systolic pressure; *EDP,* end-diastolic pressure; *ESV,* end-diastolic volume; *EDV,* end-diastolic volume.

contractility and diastolic function. These measurements are clearly needed to better understand the clinical course of pressure- and volume-overloaded right ventricles and of the timing and effects of various therapeutic interventions.

In summary, this study for the first time describes a novel method of generation of RV PVLs, via a hybrid method of right heart catheterization and RNA.

Acknowledgment

The authors have indicated they have no financial conflicts of interest.

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