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Assessment of Right Ventricular Contractile Function in Patients With Left Ventricular Dysfunction by a Simplified Echocardiographic Subtraction Method

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Abstract

A simplified version of the modified echocardiographic subtraction method for measuring right ventricular (RV) volume was used to assess the indices of RV contractile function, the end-systolic pressure-volume (RV E_{max}) ratio and the $+dP/dt_{max}$-end-diastolic volume (EDV) relationship. RV volumes determined by the simplified subtraction method and the modified subtraction method were compared in 18 patients.

Subsequently, RV contractile function was assessed in 13 patients with normal left ventricular (LV) function (control group: ejection fraction > 56%, as determined by left ventriculography), and 10 patients (group F; five with myocardial infarction, three with dilated cardiomyopathy, two with ischemic cardiomyopathy) with depressed LV function (ejection fraction ≦ 55% by left ventriculography). During the application of lower body negative pressure of −20 mmHg, B-mode echocardiograms (apical four-chamber view) and RV or pulmonary artery pressure were recorded simultaneously.

The regression equation between RV volumes obtained by the simplified subtraction method and the modified subtraction method was $y = 0.99x + 4.5$, and the correlation coefficient (r) was 0.985 ($p < 0.001$). The RV E_{max} of group F was not significantly less than that of the control group (0.40 ± 0.16 vs 0.44 ± 0.17 mmHg/m*l*, not significant). The correlation coefficients of RV E_{max} in each group were large (control group 0.92 ± 0.09, group F 0.90 ± 0.07). The $+dP/dt_{max}$-EDV ratio of group F was significantly less than that of the control group (2.05 ± 0.74 vs 3.40 ± 1.85 mmHg/m*l* · sec, $p < 0.05$). The correlation coefficient of the $+dP/dt_{max}$-EDV ratio was 0.91 ± 0.06 in the control group and 0.85 ± 0.15 in group F. The indices of RV contractile function could be assessed using the simplified subtraction method. RV function in patients with LV dysfunction appeared to be depressed.

Key Words
Ventricular function (right ventricular contractile function), Heart failure, Echocardiography (transthoracic)

INTRODUCTION

Measurement of right ventricular (RV) volume is difficult. The radionuclide method does not need any geometric assumption[1,2], but poses some difficulties in discriminating the RV. Cine magnetic resonance imaging is promising[3,4], but quite time consuming. Although the ellipsoidal shell subtraction method[5] has been used in dogs, this cannot be applied to humans, because it requires measurement

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Selected abbreviations and acronyms

dP/dt = first derivative of ventricular pressure
EDV = end-diastolic volume
EF = ejection fraction
ESV = end-systolic volume
LBNP = lower body negative pressure
LV = left ventricular
RV = right ventricular
RV E_{max} = right ventricular end-systolic pressure volume ratio

of the volume of the ventricular septum.

We reported earlier a unique method for measuring RV volume[6], the modified echocardiographic subtraction method. By this method, we can measure the RV volume by apical four- and two-chamber views. In the present study, using a simplification of this method, we assessed the indices of RV contractile function, end-systolic pressure-volume ratio (E_{max})[7-9] and $+dP/dt_{max}$-end-diastolic volume (EDV) relation[10,11]. In dogs, the instantaneous pressure-volume relationship[12-14] has been reported. In humans, a radionuclide method[15-17] and angiography[18,19] have been used to determine the RV E_{max}. However, there is no single simple method applicable clinically. Our simplified subtraction method can be carried out easily and repeatedly at the bedside. We studied its usefulness and clinical applicability in evaluating RV contractile function in patients with left ventricular (LV) dysfunction.

METHODS

In the first part of this study, we compared RV volumes obtained by the simplified subtraction method vs the modified subtraction method in 18 patients (three normal, four with angina pectoris, four with myocardial infarction, four with aortic regurgitation, and three with mitral regurgitation; **Fig. 1**). There were 14 men and 4 women aged 36 to 72 years (mean 61±12 years). Informed consent was given by all patients before the study.

In the modified subtraction method, RV volume was calculated by subtracting the entire LV (including the LV myocardium) from the entire heart (including the RV and the entire LV). Both ventricular volumes were calculated by the biplane area-length method applied to the apical four- and two-chamber views. In the simplified method, RV volume was calculated by applying the same subtraction method only to the apical four-chamber view. Instantaneous changes in RV volume can be assessed by this simplified method.

In the second part of this study, RV contractile function was assessed in 13 normal patients who had cardiac catheterization due to chest pain and were found to have normal coronary angiograms with normal LV function {control group : ejection fraction (EF)>56%, as determined by left ventriculography}, and 10 patients (group F; five with myocardial infarction including one inferior myocardial infarction without RV involvement, three with dilated cardiomyopathy without apparent RV dysfunction, two with ischemic cardiomyopathy without apparent RV dysfunction) with depressed LV function (EF≦55%, as determined by left ventriculography). Patients who had moderate or greater tricuspid regurgitation as determined by Doppler echocardiography were excluded. During the application of lower body negative pressure (LBNP) of −20 mmHg (with the patients' lower body in a tight box, with negative pressure applied by suction), B-mode echocardiograms (apical four-chamber view, 77020AC, 2.5 MHz, Hewlett Packard, USA; recorded by VCR, Victor, BRS601M, Japan) and RV or pulmonary artery pressure measured by means of a thermodilution catheter tip manometer (T-147, Goodtec, Japan) were recorded simultaneously (paper speed of 100 mm/sec).

B-mode echocardiogram (apical four-chamber view)

End-diastolic and end-systolic volumes for five or six consecutive beats just after the pressure began to decline during the application of LBNP were calculated by the simplified method (**Fig. 2–upper**).

Right ventricular and pulmonary artery pressure

End-systolic pressure from the pulmonary artery pressure or the RV pressure and maximum +dP/dt ($+dP/dt_{max}$) from the RV pressure were obtained for five or six consecutive beats just after the pressure began to decline during the application of LBNP (digitized by personal computer, Mitsubishi, MP286L, Japan, and digitizing tablet, Suma Sketch, Japan). RV end-systolic pressure was determined at the dicrotic notch of pulmonary pressure or the RV pressure at the end of the T wave of the electrocardiogram. From the volume and pressure thus ob-

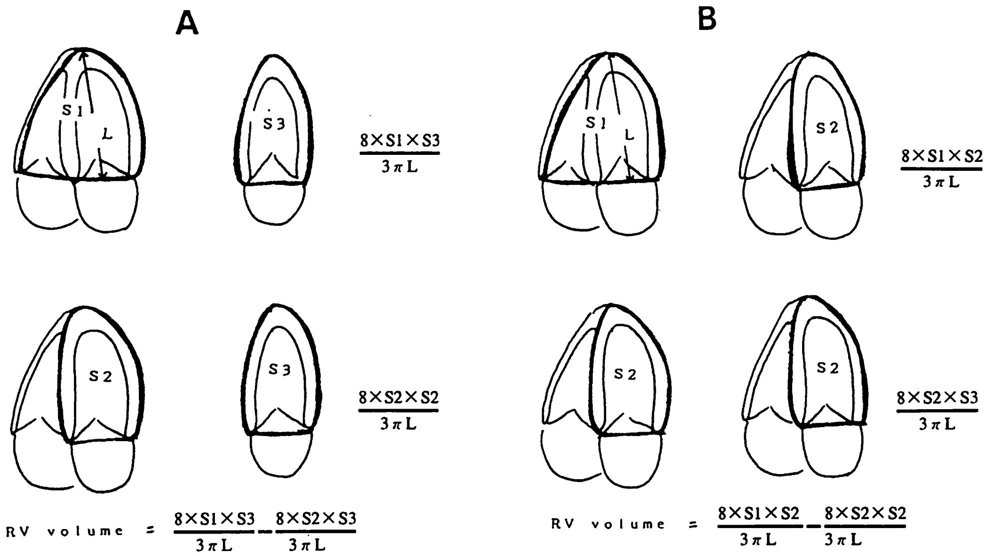

Fig. 1 Two methods for comparing RV volumes

In the modified subtraction method (*A*), right ventricular volume was calculated by subtracting the entire left ventricle (including the left ventricular myocardium) $\{(8\times S2\times S3)/3\pi L\}$ from the entire heart (including the right ventricle and the entire left ventricle) $\{(8\times S1\times S3)/3\pi L\}$.

Both ventricular volumes were calculated by the biplane area-length method applied to the apical four- and two-chamber views. In the simplified subtraction method (*B*), right ventricular volume was calculated by applying the same subtraction method solely to the apical four-chamber view $\{(8\times S1\times S2/3\pi L)-(8\times S2\times S2/3\pi L)\}$. Instantaneous changes of right ventricular volume can be assessed by this simplified method.

S1 = area of the right ventricle and the entire left ventricle (including the left ventricular myocardium) in the apical four-chamber view; S2 = area of the entire left ventricle (including the left ventricular myocardium) in the apical four-chamber view; S3 = area of the entire left ventricle (including the left ventricular myocardium) in the apical two-chamber view; L = longitudinal diameter of the ventricle.

tained, RV E_{max} and the $+dP/dt_{max}$-EDV relationship (by the least square method) were calculated and compared for the two groups (**Fig. 2–lower**).

Statistical analysis

Data are presented as mean ± standard deviation (SD). Comparisons were made by Student's unpaired *t*-test. A level of $p<0.05$ was considered significant.

RESULTS

Comparison of right ventricular volume measured by the modified subtraction method and the simplified subtraction method

In the first part of this study, RV EDV and end-systolic volume (ESV) that were measured by the simplified subtraction method were compared with those measured by the modified subtraction method in 18 patients with various heart diseases. As shown in **Fig. 3**, the regression equation was $y=0.99x+4.5$ and the correlation coefficient (r) was 0.985 ($p<0.001$). Thus, the simplified method can be used to calculate instantaneous RV volume.

Right ventricular contractile function (Tables 1, 2)

The differences in the RV EDV and RV ESV were not significant (NS) between the control group and group F (RV EDV 113±29 and 101±24 m*l*, NS; RV ESV 54±13 and 52±17 m*l*, NS). The RV end-systolic pressure at baseline was significantly increased in group F (24.5±11.6 vs 15.2±3.1 mmHg, $p<0.05$). The minimum RV end-systolic pressure during application of LBNP was also significantly higher in group F (18.2±10.3 vs 9.3±3.2 mmHg, $p<0.05$).

The RV E_{max} of group F was not significantly lower than that of the control group (0.40±0.16 vs 0.44±0.17 mmHg/m*l*, NS; **Fig. 4**). The corrected E_{max} (E_{max} multiplied by EDV) of group F did not differ significantly from that of the control group (39.0±13.4 vs 49.7±22.9 mmHg, NS). The r of E_{max} in each group was large (control group 0.92±0.09 and group F 0.90±0.07). The r values of two patients in the control group were less than 0.81.

The $+dP/dt_{max}$-EDV ratio of group F was significantly less than that of the control group (2.05±

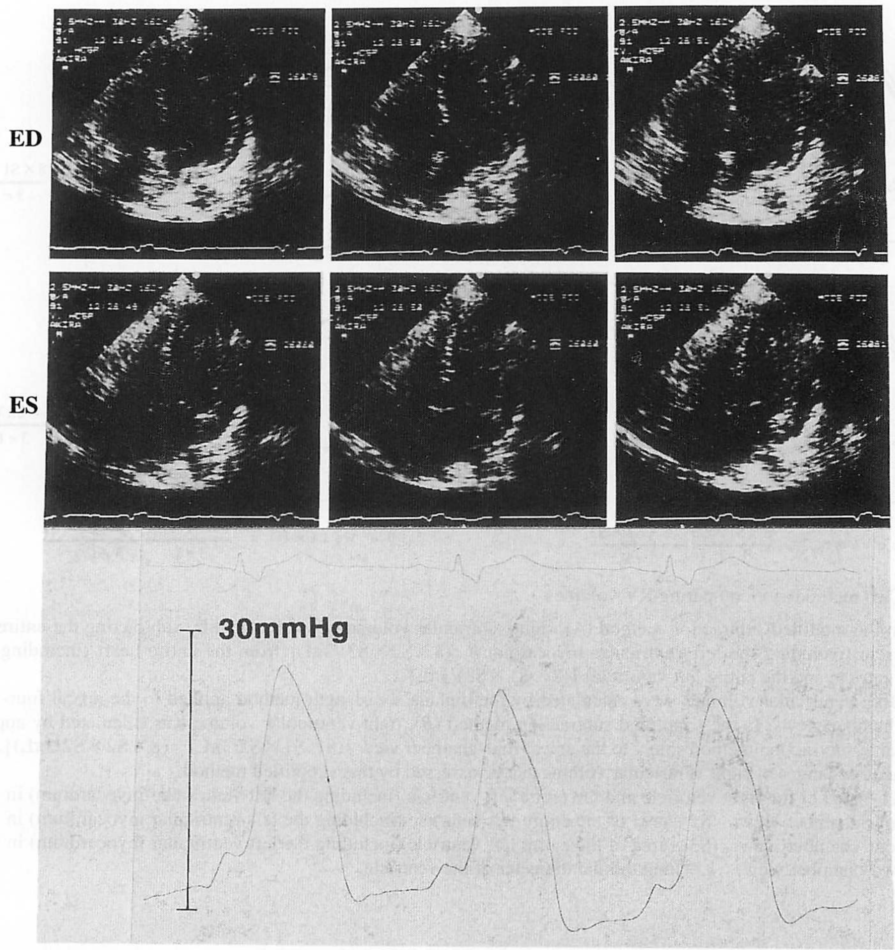

Fig. 2 Findings in a representative patient (a 56-year-old man with myocardial infarction)

Upper : Echocardiograms showing three consecutive beats in the apical four-chamber view at end-diastole (ED) and end-systole (ES). These pictures were recorded by VTR.

Lower : Simultaneously recorded right ventricular pressure tracings during the application of lower body negative pressure (−20 mmHg). There is a gradual decrease in pressure.

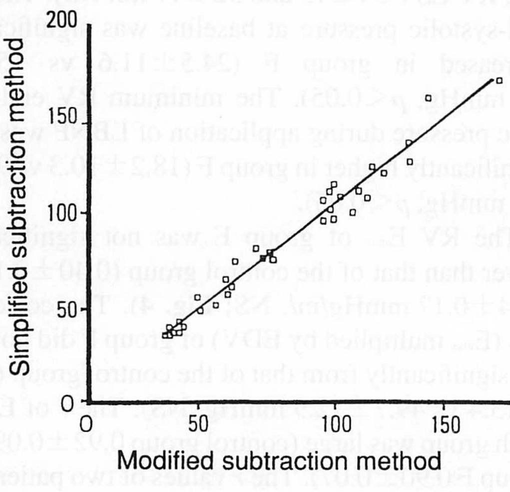

Fig. 3 Comparison of right ventricular volume measured by the modified subtraction method (abscissa) with that measured by the simplified subtraction method (ordinate)

The correlation was good with a regression equation of $y=0.99x+4.5$ ($n=36$), and correlation coefficient of 0.985 ($p<0.001$).

Table 1 Right ventricular contractile function in the control group (13 patients with normal left ventricular function)

Case (age/sex)	RVEDV (m*l*)	RVESV (m*l*)	RVEF (%)	RVESP (mmHg)	$RVESP_{min}$ (mmHg)	LVEF (%)	LVEDV (m*l*)	RV E_{max} (mmHg/m*l*)	*r*	RV $E_{max}C$ (mmHg)	$+dP/dt_{max}$-EDV (mmHg/m*l*·sec)	*r*
53/F	65	30	54	13.5	10.7	—	—	0.36	0.93	23.4	3.03	0.75
66/M	114	55	52	12.5	6.6	72	92	0.54	0.94	61.6	2.89	0.85
61/F	165	74	55	16.8	12.4	72	145	0.24	0.95	39.6	7.72	0.97
56/M	113	51	55	13.5	7.2	70	121	0.57	0.94	64.4	1.97	0.99
56/M	98	42	57	20.0	14.1	66	108	0.41	0.95	40.2	2.29	0.96
30/M	161	73	55	14.5	5.4	64	121	0.28	0.98	45.1	7.18	0.81
45/M	125	67	46	15.0	12.0	64	135	0.26	0.99	32.5	2.38	0.88
52/F	96	43	55	20.8	14.5	63	115	0.55	0.69	52.8	3.2	0.87
62/M	115	57	50	11	6.8	62	109	0.47	0.79	54.1	2.51	0.86
56/M	96	42	56	18	8.3	61	92	0.56	0.96	53.8	2.51	0.89
68/M	121	52	57	14.5	9.5	59	103	0.32	0.92	38.7	3.56	0.99
65/M	135	57	58	16.5	7.9	65	147	0.84	0.99	113.4	2.23	0.90
55/M	77	55	29	11.3	5.0	72	111	0.35	0.91	27.0	2.69	0.90
Mean±SD	113±29	54±13	52±8	15.2±3.1	9.3±3.2	66±5	117±18	0.44±0.17	0.92±0.09	49.7±22.9	3.40±1.85	0.91±0.06

RVESP=right ventricular end-systolic pressure; $RVESP_{min}$=minimum RVESP; $E_{max}C$=RVEDV×E_{max}; $+dP/dt_{max}$-EDV=right ventricular maximum +dP/dt-EDV ratio; *r*=correlation coefficient; F=female; M=male.

Table 2 Right ventricular contractile function in group F (10 patients with depressed left ventricular function)

Case (age/sex)	RVEDV (m*l*)	RVESV (m*l*)	RVEF (%)	RVESP (mmHg)	$RVESP_{min}$ (mmHg)	LVEF (%)	LVEDV (m*l*)	RV E_{max} (mmHg/m*l*)	*r*	RV $E_{max}C$ (mmHg)	$+dP/dt_{max}$-EDV (mmHg/m*l*·sec)	*r*
47/F	78	41	47	11.5	7.0	52	109	0.57	0.81	44.5	1.54	0.92
60/M	114	66	42	16.5	10.5	51	127	0.22	0.87	25.1	2.45	0.79
56/M	118	49	59	17.5	10.4	50	131	0.42	0.98	49.6	1.16	0.89
68/F	83	34	59	20.5	14.7	47	95	0.37	0.82	30.7	1.81	0.81
58/F	129	67	48	16.5	10.4	34	130	0.32	0.98	41.3	1.77	0.99
59/F	118	66	44	23.0	20.1	26	196	0.31	0.85	36.6	3.21	0.97
61/M	128	81	37	25.6	16.1	12	378	0.52	0.94	66.6	1.24	0.52
62/F	99	34	66	36.2	32.1	19	231	0.21	0.96	20.8	3.29	0.91
60/M	78	53	32	51.0	41.5	27	174	0.39	0.86	30.4	2.23	0.90
67/M	62	32	48	26.5	18.8	55	111	0.71	0.94	44.0	1.81	0.81
Mean±SD	101±24	52±17	48±10	24.5±11.6	18.2±10.3	37±16	168±85	0.40±0.16	0.90±0.07	39.0±13.4	2.05±0.74	0.85±0.15

Abbreviations as in Table 1.

0.74 vs 3.40±1.85 mmHg/m*l*·sec, $p<0.05$; **Fig. 5**). The *r* of the $+dP/dt_{max}$-EDV ratio was 0.91±0.06 in the control group and 0.85±0.15 in group F. For one normal patient and two group F patients, *r* was less than 0.81.

The LVEDV was 117±18 in the control group and 168±85 m*l* in group F (as determined by left ventriculography). The LVEF was 66±5% in the control group and 37±16% in group F ($p<0.05$; in one normal patient left ventriculography was not performed, but echocardiographic examination showed the LV function of this patient was normal).

DISCUSSION

We previously reported a convenient method for measuring RV volume, the modified echocardiographic subtraction method[6]. In this study, we have further simplified this method and applied it to the measurement of RV E_{max}. We obtained very comparable results in measurements of RV volume by the modified subtraction method and the simplified method. When we measured RV E_{max} in normal patients (control group) and in patients with LV dysfunction (group F), the *r* of RV E_{max} in each group

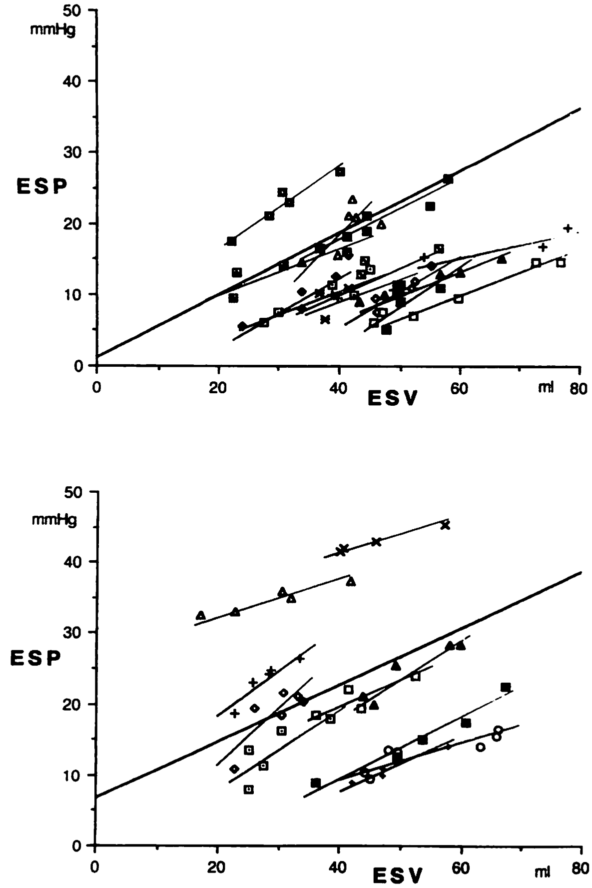

Fig. 4 Graphs of the end-systolic pressure volume points

Upper: Control group (subjects with normal LV function). The mean correlation equation was $0.44x+1.1$.
Lower: Group F (subjects with depressed LV function). The mean regression equation was $y=0.40x+6.9$. The slope of group F tended to be less than that of the control group, but the difference was not significant.

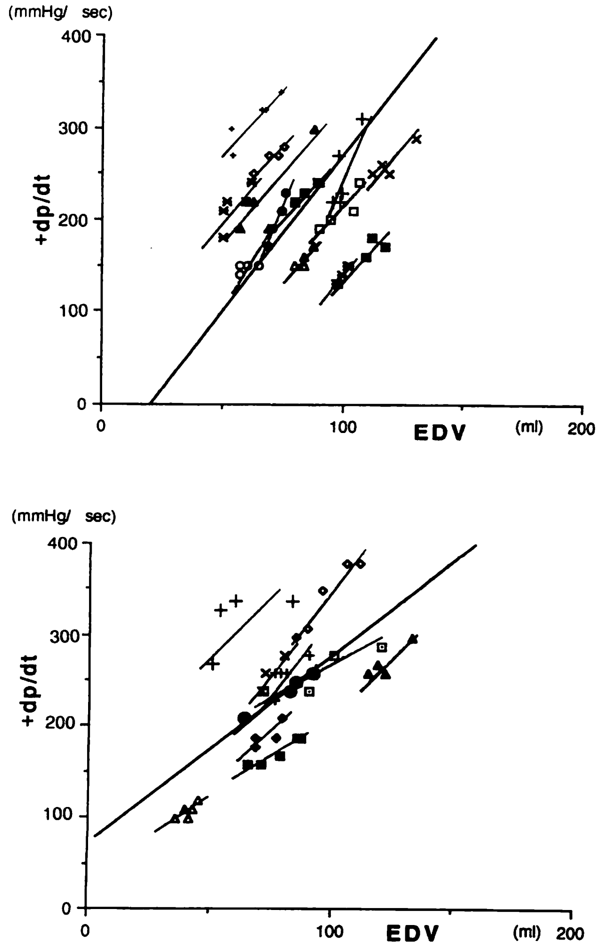

Fig. 5 Graphs of the $+dP/dt_{max}$-EDV relationship

Upper: Control group (subjects with normal LV function). The mean regression equation was $y=3.38x-67$.
Lower: Group F (subjects with depressed LV function). The mean regression equation was $y=2.06x+70$. The slope of group F was significantly less than that of the control group.

was >0.9. Although RV E_{max} in group F tended to be lower than that in the control group, the difference was not significant. The $+dP/dt_{max}$-EDV ratio of the RV was also obtained by the simplified subtraction method. Here, too, the correlation within each group was good. The $+dP/dt_{max}$-EDV ratio of RV was lower in group F than in the control group. We were able to assess the indices of RV contractile function by use of the simplified subtraction method and found that RV function in patients with LV dysfunction appeared to be depressed.

Right ventricular volume and pressure

There have been few studies of RV volume and function in patients with myocardial infarction[20,21] or dilated cardiomyopathy[3]. In a cine magnetic resonance imaging study[3], RV volume and EF in patients with dilated cardiomyopathy were normal. In our present study, the RV volume and EF of group F were not significantly increased or decreased. Although the RVEF in patients with myocardial infarction has been observed to be depressed[20,21], in our study the RVEF tended to be decreased but not significantly so. This disparity may be attributable to differences in the patients studied. The reason that RV volume was not increased and EF was not decreased in group F was probably due to the relatively mild RV dysfunction in group F. Generally, in dilated cardiomyopathy patients, dilated RV indicates end-stage heart failure or increased RV volume, and decreased RVEF indicates depressed RV contractile function.

Right ventricular end-systolic pressure volume ratio

Application of the index of LV contractile function[7-9] to RV was studied in dogs[12-14]. One study used implanted radiopaque markers[12]. A second used a volumetric chamber in a cross-circulated heart[13]. A third used a cylindrical shell subtraction method[14] that is somewhat similar to our method. Attempts have been made to assess RV E_{max}[15-17,19], including three studies[15-17] that used a radionuclide method and one[19] that used angiography. The RV E_{max} values obtained in these studies were similar to ours (0.5–1.4 mmHg/m*l* range). However, no previous study compared the RV E_{max} values of patients with LV dysfunction with those of normal patients.

Our results showed that the RV E_{max} in patients with LV dysfunction tended to be decreased, but this finding might be attributable to the small number of patients studied in our series and to the mild degree of RV dysfunction in our patients.

Right ventricular $+dP/dt_{max}$-end-diastolic volume ratio

In the LV, the $+dP/dt_{max}$-EDV ratio is one of the indices of contractile function[10] and appeared to be a more sensitive measure of contractile function than E_{max} or the stroke-work-EDV relationship[11]. One study in dogs[14] used the cylindrical shell subtraction method. Considering the magnitude of canine EDV (about half that of human volume), the slope of the $+dP/dt_{max}$-EDV ratio obtained in our study was comparable to that found in dogs (3.5 vs 14 mmHg/m*l* · sec). The reason why only the $+dP/dt_{max}$-EDV ratio was depressed significantly and the E_{max} was not decreased in group F is thought to be that the $+dP/dt_{max}$-EDV ratio is a more sensitive measure of contractile function than E_{max}. Another reason was that in our patients, the RV dysfunction appeared to be mild. The E_{max} was more reproducible than the $+dP/dt_{max}$-EDV ratio[14], but the $+dP/dt_{max}$-EDV ratio was more sensitive to detect changes in contractile state than the E_{max}[11]. Thus, we concluded that in our patients, RV contractile function was depressed to a degree that could be detected by measurement of the $+dP/dt_{max}$-EDV ratio, but not by E_{max}. The preload recruitable stroke-work-EDV relationship is the most reproducible and sensitive to changes in contractile state[14], but we did not assess that index because it requires measurement of the stroke work. Future studies might be necessary using a computerized method to measure the preload recruitable stroke-work-EDV relationship.

Interaction between right and left ventricles

Left and right ventricle interaction is known to occur transseptally, transvenously, and transpericardially. In one study of the dog[22], RV cardiac output regulated LV function. In another dog study[23], increased RV pressure augmented septal shortening and assisted the LV pump function. The effects of LV function on RV function have also been studied. A third dog study[24] showed the influence of LV isovolumic pressure on RV pressure. The findings suggested that RV pumping function is aided by the LV. In another cross-circulated heart study in dogs[25], the RV end-systolic pressure-volume relationship shifted upward with increased LV volume loading. In an electrically isolated RV free wall preparation model[26], LV contraction was shown to be a very important contributor to RV pressure and volume outflow. In a clinical study of hypertensive patients[27], RV diastolic function was abnormal. The diastolic interdependence of the two ventricles appeared to be due to the shared interventricular septum[28,29]. In another clinical study[30], when LV volume and pressure increased, the RV pressure-volume curve shifted to the left and became steeper.

Thus, in the present study, the interrelationship of the two ventricles appeared to be the main cause of depressed RV contractile function in patients with LV dysfunction, despite normal RV volume and EF. Although we found only the $+dP/dt_{max}$-EDV ratio to be decreased, examination of a large number of patients may reveal a decrease in RV E_{max}.

Clinical implications

Instantaneous changes in RV volume are easily measured by our method, and no drug is needed to obtain E_{max}. The measurement can be performed repeatedly. Making a current prognosis in patients with myocardial infarction requires true assessment of RV function. Our method of measuring RV contractile function appears to be clinically useful.

Limitations

We used only the four-chamber view, yet found a good correlation between results obtained by the simplified subtraction method and the modified subtraction method. In the future, at least two views will be done to measure RV volume, which is now impossible.

In previous measurements of RV volume by use of the modified subtraction method, we found interobserver and intraobserver variability to be within acceptable limits (14% and 11%, respectively), but computer-based automatic calculation may be preferable. In a pig study, the RV contractile state was assessed using the conductance catheter technique and this appeared to be a promising method[31]. A comparison of RV contractile states assessed by our method and by the conductance catheter technique might be informative.

Further studies in patients with RV dysfunction, *e.g.*, patients with pulmonary hypertension, are desirable.

Although the RV E_{max} and $+dP/dt_{max}$-EDV ratio values obtained by this simplified subtraction method showed an excellent correlation in more than 80% of the patients studied, in a total of five patients (two in the case of RV E_{max}, three in the case of RV $+dP/dt_{max}$-EDV), the correlation coefficient was not greater than 0.81. This might be attributed to the accuracy of RV measurement by this simplified subtraction method.

CONCLUSION

We could assess the indices of RV contractile function using of the simplified subtraction method and found that RV contractile function in patients with LV dysfunction appeared to be depressed.

要　約

心エコー図簡易サブトラクション変法を用いた左心機能低下例の右室収縮能評価

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我々は既に右室容積算出法として，独特の心エコー図サブトラクション変法を報告した．今回はその簡易化した方法を用いて右室の収縮能である右室収縮末期圧–容積関係 (右室 E_{max}) と右室最大圧立ち上がり速度–拡張末期容積関係 ($+dP/dt_{max}$–end-diastolic volume relationship) を評価した．

最初に 18 例の患者で簡易法と通常の心エコー図サブトラクション変法による右室容積を比較検討した．次いで左室造影上，左室駆出率が 56% 以上の正常群 13 例と，左室駆出率が 55% 以下の左室機能低下群 10 例 (心筋梗塞症 5 例，拡張型心筋症 3 例，虚血性心筋症 2 例) で右室収縮能を求めた．−20 mmHg の下半身陰圧の適用中に，B モード心エコー図で心尖部四腔像と右室圧または肺動脈圧を同時記録した．

簡易法と通常の心エコー図サブトラクション変法により得られた右室容積の回帰式は $y=0.99x+4.5$ で，相関係数は 0.985 ($p<0.001$) であった．右室 E_{max} は左室機能低下群では正常群に比し，有意ではないが低下傾向を示した (正常群 0.44±0.17，左室機能低下群 0.40±0.16 mmHg/m*l*，有意差なし)．両群の右室 E_{max} の相関係数は良好であった (正常群 0.92±0.09，左室機能低下群 0.90±0.07)．右室最大圧立ち上がり速度–拡張末期容積関係は左室機能低下群で正常群に比し有意に低下していた (正常群 3.40±1.85，左室機能低下群 2.05±0.74 mmHg/m*l*・sec, $p<0.05$)．右室最大圧立ち上がり速度–拡張末期容積関係の相関係数は正常群で 0.91±0.06，左室機能低下群で 0.85±0.15 であった．

以上のように，我々の心エコー図簡易サブトラクション変法により右室収縮能の評価が可能であり，左室機能低下例の検討では右室収縮能も低下していることが明らかになった．

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