PHONOCARDIOGRAPHIC APPROACH TO THE DETECTION OF RIGHT VENTRICULAR MYOCARDIAL INFARCTION

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Right ventricular myocardial infarction (RVMI) is not as rare as was previously thought and, if present, is almost always complicated with inferior myocardial infarction (IMI). On the basis of hemodynamic criteria, RVMI was identified in 33.7 percent of 98 cases with IMI. RVMI may induce a low cardiac output, if not often, resulting in cardiogenic shock. It is clearly desirable therefore to have an early and sensitive diagnostic clue to the presence or possibility of RVMI. Although much investigative attention in the diagnosis of RVMI has been focused on electrocardiography, echocardiography, radionuclide ventriculography, technetium-99 m stannous pyrophosphate scintigraphy, and thallium-201 scintigraphy, there has been little study of phonocardiography (PCG). The present study was therefore undertaken in an attempt to assess whether or not PCG information is useful for the identification of RVMI. PCG recordings were made during unforced natural respiration for at least 8 consecutive beats. From among several PCG parameters, the ΔQP_2 interval was found to be the most reliable for the identification of RVMI in patients with IMI. The ΔQP_2 interval was defined as the difference between Max QP_2 and Min QP_2 , where Max QP_2 and Min QP_2 represent the maximal and minimal interval between Q and P_2 , respectively. Using $\Delta QP_2 \leq 10$ msec, the sensitivity and specificity for the diagnosis of RVMI were 90.9% and 84.6%, respectively. These results were superior to those obtained by radionuclide ventriculography, electrocardiography and echocardiography.

We consider therefore that PCG should be recorded as soon as possible in the presence of IMI, and conclude that a small range (≤ 10 msec) of ΔQP_2 carries a reasonably high sensitivity and specificity for the diagnosis of RVMI.

THE existence of right ventricular myocardial infarction (RVMI) as a clinical entity was not recognized essentially until its hemodynamic consequences were demonstrated in 1974 by Cohn et al.¹ Subsequently, with refinement of noninvasive diagnostic techniques, it has been shown that RVMI is frequently associated with infarction of the inferoposterior wall of the left ventricle. Early recognition of RVMI is important not only because the time of onset of its

hemodynamic consequences is unpredictable and can arise as early as within the first hour after the acute event, but also because inappropriate treatment and hemodynamic alterations that might reduce the RV filling pressure and cardiac output can be avoided. In the last few years, several noninvasive techniques, including electrocardiography,²⁻⁸ echocardiography,⁹⁻¹⁴ technetium-99 m stannous pyrophosphate scintigraphy,¹⁵⁻¹⁷ radionuclide ventriculography,^{16,18-23} and thallium-201 scintigraphy^{15,24} have been employed to diagnose RVMI. However, little attention has yet been paid to the phonocardiographic approach for detecting RVMI, although this would seem desirable from an

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TABLE 1 PHONOCARDIOGRAPHIC, HEMODYNAMIC, ELECTROCARDIOGRAPHIC, ECHOCARDIOGRAPHIC, PATIENTS WITH RIGHT VENTRICULAR MYOCARDIAL INFARCTION

Patient No.	Age (yrs)	Sex	HR (bpm)	Phonocardiographic data								
				MaxA ₂ P ₂ (msec)	MinA ₂ P ₂ (msec)	ΔA ₂ P ₂ (msec)	MaxA ₂ P ₂ /MinA ₂ P ₂	MaxQA ₂ (msec)	MinQA ₂ (msec)	ΔQA ₂ (msec)	MaxQA ₂ /MinQA ₂	MaxQP ₂ (msec)
1.	65	M	87	45	40	5	1.13	330	320	10	1.03	375
2.	79	F	103	45	35	10	1.29	355	345	10	1.03	380
3.	54	M	98	40	25	15	1.60	315	300	15	1.05	330
4.	64	M	60	30	20	10	1.50	415	400	15	1.04	430
5.	48	M	58	45	30	15	1.50	410	405	5	1.01	435
6.	70	M	70	50	40	10	1.25	335	330	5	1.02	365
7.	72	F	55	45	25	15	1.80	375	365	10	1.03	400
8.	49	M	76	45	35	10	1.29	375	365	10	1.03	415
9.	65	F	61	45	30	15	1.50	445	435	10	1.02	475
10.	77	M	56	45	40	5	1.13	430	420	10	1.02	475
11.	80	M	96	30	20	10	1.50	375	350	25	1.07	400
12.	72	M	82	40	25	15	1.60	350	335	15	1.05	389
13.	71	M	60	70	65	15	1.08	370	365	5	1.01	440
14.	70	M	59	70	50	20	1.40	430	420	10	1.02	480
15.	68	F	95	35	25	10	1.40	385	365	20	1.05	410
16.	72	M	70	45	35	10	1.29	390	380	10	1.03	425
17.	60	M	72	30	30	0	1.00	410	405	5	1.01	435
18.	35	M	109	60	55	5	1.09	330	325	5	1.02	390
19.	63	M	67	40	30	20	1.33	385	385	0	1.00	425
20.	61	F	67	25	20	5	1.25	405	390	15	1.04	425
21.	63	F	60	35	30	5	1.17	400	395	5	1.01	430
22.	62	M	69	55	50	5	1.10	400	400	0	1.00	455
23.	77	M	88	30	25	5	1.20	340	325	15	1.05	375
24.	76	M	61	50	25	25	2.00	420	415	5	1.01	465
25.	62	M	62	40	15	25	2.67	415	410	5	1.01	425
26.	60	M	73	45	30	15	1.50	350	330	20	1.06	375
27.	74	M	91	35	25	10	1.40	360	345	15	1.04	375
28.	61	M	100	25	10	15	2.50	350	335	15	1.04	365
29.	57	F	72	30	15	15	2.00	375	360	15	1.04	380
30.	60	F	63	55	45	10	1.22	420	410	10	1.02	475
31.	72	M	92	35	20	15	1.75	360	355	5	1.01	365
32.	57	M	57	35	30	5	1.16	380	375	5	1.01	415
33.	64	F	83	35	20	15	1.75	390	380	10	1.03	425
Mean	64.8 ±16.0	22M 11F	74.9 ±16.0	42.0 ±11.2	30.8 ±12.2	11.4 ± 5.8	1.47 ±0.39	381.1 ± 33.3	370.9 ± 35.1	10.2 ± 5.8	1.03 ±0.02	409.5 ± 44.9

Abbreviations: HR = heart rate; Max = maximum; Min = minimum; A₂ = aortic component of the second heart sounds; P₂ = pulmonic component of the second heart sounds; QA₂ = left ventricular electromechanical systole; QP₂ = right ventricular electromechanical systole; ΔA₂P₂ = MaxA₂P₂ - MinA₂P₂; ΔQA₂ = MaxQA₂ - MinQA₂; ΔQP₂

economic and practical viewpoint.

In the present study, therefore, an attempt was made to assess whether or not phonocardiograms contain useful information for the diagnosis of acute RVMI.

METHODS

Patients

The study group comprised 98 consecutive patients admitted to the CCU of Kyorin University Hospital during 1983 and 1985 who suffered a first acute inferior myocardial infarction (IMI). Acute MI was documented from the history, evolutionary electrocardiographic (ECG) changes and significant elevations of creatinine kinase MB in the serum. A standard ECG, phonocardiogram,

AND RADIONUCLIDE VENTRICULOGRAPHIC DATA FOR 33 INFERIOR MYOCARDIAL INFARCTION

Phonocardiographic data			Hemodynamic data				ECG		2DE	RNA	
MinQP ₂ (msec)	ΔQP ₂ (msec)	MaxQP ₂ /MinQP ₂	RAP (mmHg)	PCWP (mmHg)	RAP/PCWP (mmHg)	C.I. (L/min/m ²)	Dip and plateau	ST elevation in V3R (mV)	V4R (mV)	Abnormality of RVWM	Abnormalities of RV
370	5	1.01	19.0	17.5	1.09	1.77	—	+	+	+	+
380	0	1.00	11.0	11.0	1.00	2.27	—	+	+	—	+
325	5	1.01	18.0	16.0	1.13	2.16	+	—	+	+	+
425	5	1.01	18.0	15.0	1.20	2.10	—	+	+		+
435	0	1.00	10.0	7.0	1.43	3.15	+	—	—	—	+
360	5	1.01	16.0	13.0	1.23	1.84	—	+	+		+
390	10	1.03	11.0	7.0	1.57	2.20	—	+	+	+	+
415	0	1.00	10.3	9.0	1.14	2.08	—	—	—	+	+
470	5	1.01	14.0	11.2	1.25	1.80	—	+	+	—	+
470	5	1.01	12.0	14.0	0.86	2.57	—	+	+	—	+
395	5	1.01	11.0	8.0	1.38	2.20	—	—	+	+	+
370	10	1.03	12.0	8.0	1.50	3.20	—	+	+	+	+
435	5	1.01	14.0	9.2	1.52	2.60	+	+	+	+	+
475	5	1.01	10.0	8.8	1.14	2.19	—	+	+		+
405	5	1.01	11.0	6.0	1.83	2.20	—	+	+	+	+
425	0	1.00	11.4	10.8	1.06	2.14	—	+	+	+	+
435	0	1.00	10.0	9.0	1.11	3.08	—	+	+	+	+
385	5	1.01	11.0	10.1	1.09	3.31	+	—	—		+
415	10	1.02	1.08	9.6	1.13	2.19	—	—	+		+
420	5	1.01	14.0	15.6	0.90	1.98	—	+	+		+
430	0	1.00	12.0	14.2	0.95	2.20	—	+	—	+	+
450	5	1.01	10.0	5.0	2.00	3.56	+	—	+	+	+
370	5	1.01	12.6	10.0	1.26	2.45	—	—	—	+	+
450	15	1.03	13.0	8.0	1.63	2.10	—	—	—	+	+
420	5	1.01	10.0	12.0	0.83	2.73	—	+	—		—
365	10	1.03	10.8	12.4	0.87	2.58	—	+	+	+	—
370	5	1.01	16.2	14.2	1.14	1.46	—	+	+	+	—
355	10	1.03	13.3	16.4	0.81	2.13	—	+	+	—	+
365	15	1.04	13.9	15.2	0.91	1.80	—	—	—	—	+
470	5	1.01	11.2	13.3	0.84	2.45	+	+	+	+	—
365	0	1.00	11.0	12.3	0.89	2.42	+	—	—	—	—
400	15	1.04	13.7	15.6	0.89	2.44	—	+	—	—	—
415	10	1.02	11.2	11.7	0.96	2.57	—	+	+	+	—
406.8	5.8	1.01	12.5	11.4	11.6	2.36					
± 38.9	±4.4	±0.01	± 2.5	± 3.3	±0.30	±0.48					

= MaxQP₂—MinQP₂; RAP = mean right atrial pressure; PCWP = pulmonary capillary wedge pressure; C.I. = cardiac index; ECG = electrocardiography; 2DE = two-dimensional echocardiography; and RNA = radionuclide angiography.

and 2 dimensional echocardiogram (2-DE) were obtained and hemodynamic monitoring with a Swan-Ganz catheter was initiated immediately after admission to the CCU, mostly within 6 hours after the onset of chest pain. ECG gated blood pool scanning was performed within 1 week after the onset. All patients who developed arrhythmias during the period of the above-mentioned examinations and those with lung diseases, valvular

heart diseases and cardiomyopathy were excluded from the study. Also excluded from the present study were patients who were complicated with anterior AMI, because RV function may be transiently impaired in severe anterior AMI²⁵

RVMI was diagnosed hemodynamically on the basis of both a right atrial pressure (RAP) of ≥ 10 mmHg and an RAP, pulmonary capillary wedge pressure (PCWP)

TABLE II PHONOCARDIOGRAPHIC, HEMODYNAMIC, ELECTROCARDIOGRAPHIC, ECHOCARDIOGRAPHIC, PATIENTS WITH RIGHT VENTRICULAR MYOCARDIAL INFARCTION

Patient No.	Age (yrs)	Sex	HR (bpm)	Phonocardiographic data								
				MaxA ₂ P ₂ (msec)	MinA ₂ P ₂ (msec)	ΔA ₂ P ₂ (msec)	MaxA ₂ P ₂ /MinA ₂ P ₂	MaxQA ₂ (msec)	MinQA ₂ (msec)	ΔQA ₂ (msec)	MaxQA ₂ /MinQA ₂	MaxQP ₂ (msec)
1.	65	M	72	35	30	5	11.7	380	375	5	1.01	420
2.	74	F	109	30	25	5	1.20	350	340	10	1.03	380
3.	56	M	86	35	20	15	1.75	355	345	10	1.03	390
4.	85	F	86	55	45	10	1.22	355	335	20	1.06	400
5.	68	M	53	40	30	10	1.33	425	410	15	1.04	450
6.	62	M	60	45	20	20	1.80	415	395	20	1.05	440
7.	82	M	63	35	25	10	1.40	395	375	20	1.05	420
8.	75	F	67	55	45	10	1.22	415	405	10	1.02	455
9.	62	M	113	65	55	10	1.18	345	340	5	1.01	405
10.	68	M	86	40	25	20	2.00	360	350	10	1.03	395
11.	56	M	88	45	20	25	2.25	405	395	10	1.03	445
12.	70	M	58	50	30	15	1.43	340	330	10	1.03	375
13.	66	M	49	45	35	10	1.29	435	425	10	1.02	470
14.	65	F	130	55	15	40	3.67	290	260	30	1.12	325
15.	66	M	61	30	25	5	1.20	435	400	35	1.09	465
16.	43	M	86	65	45	20	1.47	365	350	15	1.04	410
17.	72	M	83	55	25	30	2.20	350	335	15	1.04	385
18.	60	M	63	50	45	10	1.24	365	350	15	1.04	405
19.	57	M	77	45	20	15	2.20	375	355	20	1.04	400
20.	62	M	80	40	20	20	2.05	370	355	15	1.06	400
21.	67	M	78	50	40	10	1.25	370	360	10	1.04	420
22.	37	F	103	35	30	5	1.10	330	325	5	1.03	360
23.	52	M	83	50	40	10	1.25	360	350	10	1.02	410
24.	59	M	88	45	20	15	1.17	330	310	20	1.03	370
25.	73	M	98	35	25	10	1.25	335	325	10	1.07	360
26.	55	M	85	30	25	10	1.80	370	360	10	1.03	400
27.	70	M	86	30	30	0	1.40	395	390	5	1.03	435
28.	77	M	57	50	30	15	1.50	375	370	5	1.01	420
29.	71	M	82	55	35	20	1.57	430	405	25	1.01	470
30.	64	M	61	55	45	5	1.22	410	390	20	1.06	475
31.	56	M	75	50	25	30	2.50	410	380	30	1.05	440
32.	70	M	90	50	40	15	0.11	355	345	10	1.08	410
33.	55	M	74	70	45	30	1.75	380	375	5	1.03	445
34.	54	M	86	35	30	5	1.17	335	325	10	1.01	380
35.	59	M	98	45	40	5	1.13	340	330	10	1.03	380
36.	50	M	96	40	20	20	2.00	340	335	5	1.03	385
37.	64	F	81	20	15	5	1.33	410	405	5	1.01	440
38.	61	M	55	45	35	10	1.29	420	405	15	1.01	450
39.	59	M	97	50	35	15	1.43	345	330	15	1.04	390
40.	77	M	89	50	30	20	1.67	370	360	10	1.05	425
41.	74	F	94	45	25	20	1.80	285	265	20	1.03	315
42.	64	M	68	45	30	15	1.50	390	375	15	1.08	450
43.	53	M	102	65	35	30	1.86	350	340	10	1.04	410
44.	37	F	85	70	35	35	2.00	380	380	0	1.03	415
45.	51	M	84	45	35	10	1.29	365	350	15	1.00	410
46.	52	M	88	50	45	5	1.11	365	360	5	1.04	415
47.	71	F	67	50	40	10	1.25	420	405	15	1.01	480
48.	74	M	107	50	30	20	1.67	325	310	15	1.04	365
49.	71	M	65	60	50	30	1.20	415	405	10	1.05	480
50.	70	M	65	55	30	15	2.83	415	400	15	1.02	455

(Continue)

AND RADIONUCLIDE VENTRICULOGRAPHIC DATA FOR 65 INFERIOR MYOCARDIAL INFARCTION

Phonocardiographic data			Hemodynamic data				ECG		2DE	RNA	
MinQP ₂ (msec)	ΔQP ₂ (msec)	MaxQP ₂ /MinQP ₂	RAP (mmHg)	PCWP (mmHg)	RAP/PCWP (mmHg)	C.I. (L/min/m ²)	Dip and plateau	ST elevation in V _{3R} (mV)	V _{4R} (mV)	Abnormality of RVWM	Abnormalities of RV
405	15	1.04	4.7	1.3	0.62	3.74	—	—	—	—	—
370	10	1.03	13.0	19.0	0.68	1.56	—	—	—	—	+
375	15	1.04	8.4	11.9	0.71	4.72	—	—	—	—	+
375	25	1.07	8.3	13.8	0.60	2.30	—	—	—	—	—
435	15	1.03	5.5	23.5	0.23	2.31	—	+	—	—	—
415	25	1.06	6.0	10.2	0.59	5.21	—	—	+	+	—
405	15	1.04	5.0	8.0	0.63	3.82	—	+	—	—	—
445	10	1.02	5.0	24.0	0.21	3.93	—	—	—	—	—
390	15	1.04	5.0	3.0	1.67	3.40	—	—	—	—	—
375	20	1.05	6.0	11.0	0.55	4.61	—	+	+	+	—
430	15	1.03	7.9	9.0	0.38	3.44	—	—	—	—	—
360	15	1.04	4.0	9.0	0.44	2.67	—	+	+	—	+
450	20	1.04	6.8	14.6	0.47	2.20	—	—	—	—	—
300	25	1.08	3.0	7.6	0.39	4.54	—	—	—	—	—
445	20	1.04	6.0	8.0	0.75	3.50	—	+	—	+	—
385	25	1.06	6.0	11.0	0.55	2.56	—	—	—	—	—
360	25	1.07	5.0	14.0	0.36	4.82	—	—	—	—	—
390	15	1.04	4.2	19.6	0.21	2.14	—	—	—	—	—
395	5	1.01	4.0	11.0	0.36	5.40	—	—	—	—	—
375	25	1.07	2.0	18.0	0.11	3.21	—	—	—	—	—
410	10	1.02	9.0	18.0	0.56	2.10	—	—	—	—	—
345	15	1.04	8.6	14.5	0.59	1.34	—	+	—	—	—
390	20	1.05	11.2	15.6	0.71	4.78	—	—	—	—	+
355	15	1.04	10.8	20.5	0.53	2.58	—	—	+	+	+
355	5	1.01	4.4	5.8	0.76	1.94	—	—	—	—	+
380	20	1.05	6.2	10.9	0.57	4.79	—	+	+	—	—
420	15	1.04	10.6	18.9	0.56	2.20	—	—	—	+	+
405	15	1.04	4.0	8.0	0.50	5.10	—	—	+	—	—
455	15	1.03	7.2	8.4	0.86	4.91	—	—	—	—	—
455	20	1.04	3.0	16.0	0.19	3.04	—	+	—	—	—
430	10	1.02	2.0	18.0	0.11	2.38	—	—	—	—	—
390	20	1.05	15.0	19.0	0.63	3.01	—	+	+	—	+
415	30	1.07	7.6	8.9	0.62	4.59	—	—	—	—	—
360	20	1.06	6.8	10.1	0.77	3.44	—	+	+	+	—
375	5	1.01	4.0	8.0	0.75	5.10	—	—	—	—	—
365	20	1.05	4.0	5.0	0.80	5.46	—	+	+	—	—
425	15	1.04	5.0	6.0	0.67	4.57	—	—	—	—	—
440	10	1.02	0.5	23.5	0.23	3.16	—	+	+	+	—
375	15	1.04	1.5	6.2	0.08	3.08	—	—	—	—	—
410	15	1.04	7.0	6.0	0.17	2.80	—	—	—	—	—
300	15	1.05	7.1	29.8	0.24	1.65	—	—	+	—	—
430	20	1.05	7.0	15.0	0.47	2.50	—	+	+	—	—
390	20	1.05	4.0	6.8	0.60	3.49	—	+	+	+	—
400	15	1.04	3.9	6.5	0.60	3.40	—	—	—	—	—
390	20	1.05	3.2	14.0	0.23	2.63	—	—	+	—	—
410	5	1.01	2.6	7.4	0.35	3.00	—	—	—	—	—
460	20	1.04	6.4	7.4	0.86	4.10	—	—	—	—	—
360	5	1.01	5.7	8.2	0.70	2.32	—	—	—	—	—
465	15	1.03	8.3	10.5	0.45	2.83	—	+	+	—	—
440	15	1.03	8.5	12.0	0.85	2.03	—	—	—	—	+

(Continue)

Patient No.	Age (yrs)	Sex	HR (bpm)	Phonocardiographic data								
				MaxA ₂ P ₂ (msec)	MinA ₂ P ₂ (msec)	ΔA ₂ P ₂ (msec)	MaxA ₂ P ₂ /MinA ₂ P ₂	MaxQA ₂ (msec)	MinQA ₂ (msec)	ΔQA ₂ (msec)	MaxQA ₂ /MinQA ₂	MaxQP ₂ (msec)
51.	51	M	83	65	30	15	1.17	400	390	10	1.04	465
52.	63	M	77	45	30	15	1.50	355	350	5	1.03	400
53.	49	M	73	60	45	15	1.33	395	385	10	1.01	445
54.	44	M	66	45	30	5	1.50	390	380	10	1.03	430
55.	69	M	70	40	30	10	1.33	375	360	15	1.03	410
56.	77	F	78	55	50	15	1.10	375	370	5	1.04	435
57.	68	F	76	40	30	20	1.33	365	355	10	1.01	495
58.	54	M	58	35	20	35	1.75	380	370	10	1.03	415
59.	62	M	83	60	35	25	2.71	345	330	15	1.05	400
60.	45	M	66	55	25	10	1.20	440	430	10	1.02	490
61.	64	M	94	60	40	10	1.50	345	335	10	1.03	405
62.	71	M	73	50	40	10	2.25	400	390	10	1.03	450
63.	86	F	73	25	10	15	1.50	380	365	15	1.04	400
64.	52	M	81	55	35	20	2.57	380	365	15	1.04	420
65.	52	M	57	55	20	35	1.75	410	380	30	1.08	450
Mean	62.6 ±10.8	53M 12F	79.5 ±15.9	47.5 ±10.9	31.7 ± 9.7	15.6 ± 9.0	1.57 ±0.50	375.1 ± 33.8	362.2 ± 33.6	12.8 ± 6.8	1.04 ±0.02	418.5 ± 37.2

Abbreviations: HR = heart rate; Max = maximum; Min = minimum; A₂ = aortic component of the second heart sounds; P₂ = pulmonic component of the second heart sounds; QA₂ = left ventricular electromechanical systole; QP₂ = right ventricular electromechanical systole; ΔA₂P₂ = MaxA₂P₂ - MinA₂P₂; ΔQA₂ = MaxQA₂ - MinQA₂; ΔQP₂

TABLE III SUMMARY OF THE PHONOCARDIOGRAPHIC

Diagnosis	n	Age (yrs)	HR (bpm)	Phonocardiographic data					
				MaxA ₂ P ₂ (msec)	MinA ₂ P ₂ (msec)	ΔA ₂ P ₂ (msec)	MaxA ₂ P ₂ /MinA ₂ P ₂	MaxQA ₂ (msec)	MinQA ₂ (msec)
Inferior MI with RVTMI	33	64.8 ±16.0	74.9 ±16.0	42.0 ±11.2	30.8 ±12.2	11.4 ± 5.8	1.47 ±0.39	381.1 ± 33.3	370.9 ± 35.1
Inferior MI without RVTMI	65	62.6 ±10.8	79.5 ±15.9	47.5 ±10.9	31.7 ± 9.7	15.6 ± 9.0	1.57 ±0.50	375.1 ± 33.6	362.2 ± 33.8
P value		NS	NS	NS	NS	*	NS	NS	NS

Abbreviations: HR = heart rate; Max = maximum; Min = minimum; A₂ = aortic component of the second heart sounds; QA₂ = left ventricular electromechanical systole; QP₂ = right ventricular electromechanical systole; ΔA₂P₂ = MaxA₂P₂ - MinA₂P₂; ΔQA₂ = MaxQA₂ - MinQA₂; ΔQP₂ =

ratio of ≥ 0.8 ¹²

The patients were classified into the following 2 groups: Group 1, 33 IMI patients with RVTMI (22 males and 11 females aged 35-80 years with a mean age of 74.9 ± 16.0 years); and Group 2, 65 IMI patients without RVTMI (31 males and 6 females aged 37-86 with a mean age of 62.6 ± 10.8 years).

Phonocardiography

Phonocardiograms, carotid pulse tracings and ECGs were recorded simultaneously on a Siemens-Elema Mingograf 62 at a paper speed of 100 mm/sec. We employed the ECG lead that most clearly demonstrated the onset of ventricular depolarization, usually lead II or a precordial lead. A con-

Phonocardiographic data			Hemodynamic data				ECG		2DE	RNA	
MinQP ₂ (msec)	ΔQP ₂ (msec)	MaxQP ₂ /MinQP ₂	RAP (mmHg)	PCWP (mmHg)	RAP/PCWP (mmHg)	C.I. (L/min/m ²)	Dip and plateau	ST elevation in V _{3R} (mV)	V _{4R} (mV)	Abnormality of RVWM	Abnormalities of RV
435	30	1.07	4.3	0.6	1.65	2.91	—	+	—	+	—
380	20	1.05	4.0	11.0	0.40	3.56	—	—	—	—	—
435	15	1.03	5.0	17.0	0.45	3.40	—	—	—	—	+
410	15	1.04	6.0	7.0	0.86	2.80	—	—	—	—	—
390	20	1.05	4.7	1.3	3.61	2.40	—	—	+	—	—
410	25	1.06	4.7	10.4	0.45	2.51	—	—	—	—	—
480	15	1.03	3.5	13.0	0.27	2.52	—	—	—	—	—
400	15	1.04	3.5	9.6	0.36	2.87	—	—	—	—	—
375	25	1.07	6.6	11.5	0.57	4.18	—	+	+	—	—
475	15	1.03	5.9	10.5	0.56	2.90	—	—	—	+	—
385	20	1.05	5.0	12.0	0.42	3.15	—	—	—	—	—
435	15	1.03	7.0	13.0	0.54	2.50	—	—	—	—	—
380	20	1.05	2.0	7.0	0.29	1.30	—	—	—	—	—
400	20	1.05	1.0	9.0	0.11	2.96	—	—	—	—	—
430	20	1.05	1.0	8.0	0.13	2.80	—	+	—	—	—
401.5	17.0	1.04	5.54	11.6	0.62	3.25					
± 37.1	± 5.7	± 0.04	± 2.7	± 5.8	± 0.61	± 1.07					

= MaxQP₂ - MinQP₂; RAP = mean right atrial pressure; PCWP = pulmonary capillary wedge pressure; C.I. = cardiac index; ECG = electrocardiography; 2DE = two-dimensional echocardiography; and RNA = radionuclide angiography.

AND HEMODYNAMIC DATA

Phonocardiographic data					Hemodynamic data				
ΔQA ₂ (msec)	MaxQA ₂ /MinQA ₂	MaxQP ₂ (msec)	MinQP ₂ (msec)	ΔQP ₂ (msec)	MaxQP ₂ /MinQP ₂	RAP (mmHg)	PCWP (mmHg)	RAP/PCWP (mmHg)	C.I. (L/min/m ²)
10.2	1.03	409.5	406.8	5.8	1.01	12.5	11.4	1.16	2.36
± 5.8	± 0.02	± 44.9	± 38.9	± 4.4	± 0.01	± 2.5	± 3.3	± 0.30	± 0.48
12.8	1.04	418.5	401.5	17.0	1.04	5.5	11.6	0.62	3.25
± 6.8	± 0.02	± 37.2	± 37.1	± 5.7	± 0.04	± 2.7	± 5.8	± 0.61	± 1.07
NS	NS	NS	NS	***	***	***	NS	***	**

MaxQP₂ - MinQP₂; RAP = mean right atrial pressure; PCWP = pulmonary capillary wedge pressure; C.I. = cardiac index

****p* < 0.001, ***p* < 0.01, **p* < 0.05, NS = not significant

tact microphone of an acceleration type (Fukuda MA 250) was placed at the most suitable position for recording the second heart sounds. The carotid arterial pulse was recorded using a pick up with a time constant of 2.0 (Fukuda TPY 303). The carotid arterial pulse was employed for identification of the aortic (A₂) and pulmonic (P₂) compo-

nents of the second heart sounds. All recordings were made during unforced respiration for at least 8 consecutive beats, and immediately before hemodynamic recordings by Swan-Ganz catheterization. The following phonocardiographic parameters were measured: (1) the maximal and minimal intervals between A₂ and the P₂, Max A₂ P₂; (2) the

Fig.1. Distribution of ΔQP_2 in the groups studied.
MI=myocardial infarction; RVMI=right ventricular myocardial infarction

Fig.2. Distribution of $MaxQP_2/MinQP_2$ in the groups studied.
MI=myocardial infarction; RVMI=right ventricular myocardial infarction

difference between $Max A_2P_2$ and $Min A_2P_2$; (3) the $Max A_2P_2/Min A_2P_2$ ratio; (4) the maximal and minimal interval between the onset of the QRS complex (Q) and A_2 , $Max QA_2$ and $Min QA_2$; (5) the difference between $Max QA_2$ and $Min QA_2$, ΔQA_2 ; (6) the $Max QA_2/Min QA_2$ ratio; (7) the maximal and minimal interval between Q and P_2 , $Max QP_2$ and $Min QP_2$; (8) the difference between $Max QP_2$ and $Min QP_2$, ΔQP_2 ; and (9) the $Max QP_2/Min QP_2$ ratio.

Radionuclide ventriculography

The patients underwent gated radionuclide equilibrium ventriculography in the modified left anterior oblique position and scintigraphy with 99 m TC-PYP allowing the best distinction between the left and right ventricles. Data collection was performed with a standard gamma scintillation camera (Toshiba GCA-401) equipped with a low energy, all-purpose parallel-hole collimator and interfaced with a dedicated on-line computer system (Toshiba nuclear medical data proces-

sing system GMS-80B). After blood pool equilibration, 6000 kilocounts were collected by the multi-gated method in which the R-R interval of the ECG was divided into 20 equal segments. Based on these data, the time activity curve at each pixel was subjected to Fourier transformation, and the phase and amplitude images of the first harmonics were prepared. On the basis of radionuclide angiography, RVMI was identified when two or more of the following criteria were satisfied: (1) a right ventricular ejection fraction (RVEF) of 40%, (2) the presence of abnormal wall motion in the RV, and (3) the presence of a delayed phase area or low amplitude area in the RV.

Two-dimensional echocardiography (2-DE)

2-DE was performed with a composite system of Toshiba SSH-40A and SDS-10A (emission frequency, 3.5 MHz). The right ventricular free wall was imaged in the 4 chamber view and short-axis view. A di-

TABLE IV

	Sensitivity (%)	Specificity (%)	Predictive value (%)	Predictive accuracy (%)
$\Delta QP_2 \leq 10 \text{ msec}$	90.9	84.6	75.0	86.7
$\text{MaxQP}_2/\text{MinQP}_2 \leq 1.01$	72.7	92.3	83.9	87.8
Abnormality of right ventricle by RNA	78.8	82.8	72.2	81.3
Abnormality of right ventricular wall motion by 2DE	69.2	78.3	47.4	75.0
ST elevation in $V_{3R} \leq 0.05 \text{ mV}$	66.8	70.8	53.7	69.4
ST elevation in $V_{4R} \leq 0.05 \text{ mV}$	69.7	72.3	56.1	71.4

agnosis of RVMI was made according to findings of hypokinesis or akinesis of the right ventricular free wall.

Electrocardiography

A standard 12-lead ECG with right precordial leads V_{1R} to V_{6R} was recorded in each patient. The position of leads V_{1R} to V_{6R} was a mirror image of that of leads V_1 to V_6 . Lead V_{1R} was placed in the fourth intercostal space at the left sternal border, V_{2R} in the fourth intercostal space at the right sternal border, V_{4R} in the fifth intercostal space at the right mid-clavicular line, V_{3R} midway between V_{2R} and V_{4R} , V_{5R} in the right anterior axillary line at the horizontal level of V_{4R} , and V_{6R} in the right mid-axillary line at the horizontal level of V_{4R} . All ECGs were standardized to 1 mV. Leads V_{1R} to V_{6R} were evaluated for the presence or absence of at least 0.05 mV elevation above the T-P segment measured 0.02 sec after the J point.

Hemodynamic measurements

The Swan-Ganz catheter was inserted via the right internal jugular vein or the right or left femoral vein. The mean PAP, mean PCWP and cardiac index were determined immediately after recording the phonocardiograms.

Statistical analysis

All data were expressed as the mean $\pm$ SD. Group comparisons were made by the nonpaired Student's *t* test. A *p* value of <0.05 was considered significant. Sensitivity, specificity, predictive value and predictive accuracy were defined as follows: sensitivity = (true positives) / (true positives + false negatives) $\times 100$; specificity = (true

negatives) / (true negatives + false positives) $\times 100$; predictive value = (true positives) / (true positives + false positives) $\times 100$; and predictive accuracy = (true positives + true negatives) / (all tests) $\times 100$.

RESULTS

Table I, II, and III show pertinent phonocardiographic, hemodynamic, electrocardiographic, echocardiographic, and radio-nuclide ventriculographic data for the IMI patients with and without RVMI. IMI was accompanied by RVMI in 33.7 percent of the 98 cases in this series. This figure is intermediate among previously reported incidences, which range from 25 to 45 percent, in patients with IMI^{15,16,18,26,27}

Phonocardiographic findings

The ΔQP_2 interval was 5.8 ± 4.4 msec in Group 1 and 17.5 ± 5.7 msec in Group 2. As demonstrated in Fig. 1, ΔQP_2 was 10 msec or below in 30 (90.9%) of the 33 patients in Group 1 but in only 10 (15.4%) of the 65 patients in Group 2. The data in Table 4 show that RVMI could be detected in patients with IMI from the criterion of ΔQP_2 being 10 msec or below, with a sensitivity of 90.9%, specificity of 84.6%, predictive value of 75.0%, and predictive accuracy of 86.7%.

The Max QP_2 /Min QP_2 ratio was examined to eliminate the effects of heart rate on the QP_2 interval. Its value was 1.01 ± 0.01 in Group 1 and 1.04 ± 0.04 in Group 2. As shown in Fig. 2, this ratio was 1.01 or below in 24 (72.7%) of the 33 patients in Group 1 but in only 9 (13.8%) of the 65 patients in Group 2. Thus, as demon-

strated in Table IV, the diagnosis of RVMI in patients with acute IMI from the criterion of Max QP₂/Min QP₂ being 1.01 or below had a sensitivity of 72.7%, specificity of 92.3%, predictive value of 83.9%, and predictive accuracy of 87.8%.

The A₂P₂ interval was shorter in Group 1 (11.4±5.8 msec) than in Group 2 (15.6±9.0 msec) ($p<0.05$). However, this parameter was of less for the detection of RVMI than either Δ QP₂ or Max QP₂/Min QP₂. Other phonocardiographic parameters, age and heart rate did not display any significant difference between Group 1 and Group 2.

Radionuclide ventriculography

Radionuclide ventriculography indicated that RVMI might exist in 78.8% of the 33 subjects in Group 1, whereas it was found in 16.9% of 59 subjects in Group 2. As demonstrated in Table IV, on the basis of these findings, the sensitivity, specificity, predictive value and predictive accuracy for the diagnosis of RVMI were estimated to be 78.8%, 82.8%, 72.2% and 81.3%, respectively.

Echocardiographic findings

2-DE, in which the RV endocardium was adequately visualized for detailed analysis of the RV wall motion, was obtained in 26 patients (78.8%) of Group 1 and 46 (70.8%) of Group 2. Either akinesis or hypokinesis of the RV wall was observed in 18 cases (69.2%) of Group 1 and 10 (21.7%) of Group 2. On the basis of the RV wall motion abnormalities, the sensitivity, specificity, predictive value and predictive accuracy for the diagnosis of RVMI were estimated to be 69.2%, 78.3%, 47.4% and 75.0%, respectively (Table IV).

Electrocardiographic findings

An ST elevation in V_{3R} equal to or greater than 0.05 mV was found in 22 cases (66.7%) of Group 1 and 19 (29.2%) of Group 2. From these findings, the sensitivity, specificity, predictive value and predictive accuracy for the diagnosis of RVMI were estimated to be 66.7%, 70.8%, 53.7% and 69.4%, respectively (Table IV). On the other, an ST elevation in V_{4R} equal to or greater than 0.05 mV was found in 23 patients (69.7%) of Group 1 and 17 (26.1%) of Group 2. As shown in Table IV, on the basis of this ST elevation in V_{4R}, the sensitivity, specificity, predictive value and predictive accuracy for

the diagnosis of RVMI were estimated to be 69.7%, 72.3%, 56.1% and 71.4%, respectively.

Hemodynamic findings

RAP was significantly higher in Group 1 (12.5±2.5 mmHg) than in Group 2 (5.5±2.7 mmHg) ($p<0.001$). The RAP/PCWP ratio was also significantly higher in Group 1 (1.16±0.30) than in Group 2 (0.62±0.61) ($p<0.001$). A dip and plateau pattern in the RV pressure tracing was observed in only 7 of 33 subjects (21.2%) in Group 1, but in none of the Group 2 subjects.

DISCUSSION

Various proposals have been put forward for the identification of RVMI depending on the diagnostic techniques used²⁻²⁴. However, only hemodynamic findings have been validated against necropsy-proven RV necrosis, thereby establishing hemodynamic criteria as the most accurate markers of RVMI²⁸. For this reason, in order to select hemodynamically important cases of RVMI, patients who showed both an RAP of ≥ 10 mmHg and an RAP/PCWP ratio of ≥ 0.8 were chosen for analysis in the present study.

Phonocardiograms: The QP₂ interval in normal subjects is reported to be prolonged by a mean of 32.6 msec during inspiration²⁹. This phenomenon is explained on the basis of a delay in the closure of the pulmonary valve due to an increase in the stroke volume from the right ventricle secondary to an increase in the venous return during inspiration²⁹. Perloff and Harvey suggested that prolongation of the QP₂ interval was smaller in individuals with a reduced capacity of right ventricular dilatation as compared with normal subjects, because such a ventricle could not provoke a sufficient increase in the stroke volume in response to an increase in the venous return during inspiration³⁰. The right ventricle dilates with the development of RVMI, but this dilatation may be limited by the pericardium³¹⁻³³. If normal diastolic distension of the RV is severely restricted by the development of acute RVMI, venous return to the RV would be considerably reduced. Under such circumstances, respiratory variation of the

venous return would also be impaired, resulting in a relative constancy of right ventricular output. Consequently, the respiratory variation in the QP_2 interval be expected to be small. In reality, the respiratory variations of the QP_2 interval, represented in this study by ΔQP_2 and $\text{Max } QP_2/\text{Min } QP_2$, were significantly smaller in patients with RVMI than in those without RVMI. The sensitivity, predictive value and predictive accuracy for the diagnosis of RVMI were 90.9%, 84.6%, 75.0% and 86.7% with $\Delta QP_2 \leq 10$ msec, and 72.7%, 92.3%, 83.9% and 87.8% with $\text{Max } QP_2/\text{Min } QP_2 \leq 1.01$, respectively. To prove the validity of the above-mentioned hypothesis, the stroke volume of the RV must be accurately determined for each pulse. Although the pulse-Doppler technique appears theoretically the most appropriate for this purpose, precise fixation of the three-dimensional angle between the sample volume and the blood flow is actually quite difficult. Therefore, beat-to-beat variations of the stroke volume calculated by the pulse-Doppler technique may be due to respiratory changes in the venous return or simply due to technical problems in setting the sample volume. Confirmation of the validity of our hypothesis must await further studies.

Radionuclide ventriculography: The ECGs, phonocardiograms, and echocardiograms were recorded immediately after admission to the CCU. However, the radionuclide ventriculography was, for various reasons, performed much later, mostly about one week after admission. We occasionally observe that abnormalities such as a delayed phase area or low amplitude area in the RV emerge only a few days after the onset of AMI. It seems likely therefore that abnormalities indicative of RVMI on the radionuclide angiography would already have disappeared in some cases by the time the radionuclide ventriculography was performed. In the present study, the data obtained from gated blood pool scintigraphic images did show a high sensitivity (78.8%) and specificity (72.3%) for the diagnosis of RVMI. However, it is possible that our results are still underevaluated for the above-mentioned reasons.

2-DE: Optimal imaging of the RV on 2-DE was possible in only 73.5% of the 96

cases. In other words, one quarter of our cases were missed from the analysis because of technical problems in recording the RV wall motion. Furthermore, akinesis of the RV wall motion on 2-DE produced a relatively low sensitivity (69.2%) and specificity (78.3%).

Electrocardiograms: Our data indicated that a 0.05 mV or greater ST elevation in V_{3R} and V_{4R} was both less sensitive (66.7% and 69.7%, respectively) and specific (70.8% and 72.3%, respectively) in identifying RVMI, when compared with previous studies^{4,5,8}. This may be due, among several other factors, to the difference in the standard for the selection of RVMI. As for the difference in diagnostic accuracy of the electrocardiographic V_{3R} and V_{4R} , it should also be remembered that ST elevation in V_{3R} or V_{4R} is often a very transient finding, which disappears sometimes within 2 hours after the onset of chest pain⁵.

Our results may thus underestimate the diagnostic accuracy of V_{3R} and V_{4R} .

Potential limitations

Identification of A_2 and P_2 may not be distinct in some cases. In most of these cases, however, clearer separation of the second heart sounds can be recorded by careful adjustment of the position of the microphone. Since the selection of RVMI was based solely on the above-mentioned hemodynamic criteria, it seems likely that a patient in whom RVMI did not cause significant hemodynamic alterations, would be falsely identified as a subject without RVMI.

Clinical implications

Phonocardiography can be performed readily and repeatedly at the bedside with great safety and at low cost. ΔQP_2 can be determined only by calculating the difference between the maximum and minimum QP_2 intervals on phonocardiograms recorded during the period of a few respirations. $\Delta QP_2 \leq 10$ msec was found to be a very useful and early simple warning signal of the likely existence of hemodynamically important RVMI. Thus, if the presence of RVMI is suggested by the ΔQP_2 value, much closer hemodynamic monitoring should be initiated so that appropriate treatment can be promptly instituted.

Conclusion

It is concluded that a small range of ΔQP_2

($\leq$ msec) in the presence of IMI is a sensitive clue to the association of RVMI with an estimated sensitivity of 90.9% and a specificity of 84.6%

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