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# Influences of ventricular pacing on hemodynamics, myocardial metabolism, and cardiac work efficiency: potential risks of rate-responsive ventricular pacing.

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## Abstract

The influences of ventricular pacing at a rate of 70 beats/min (bpm) on the systemic and coronary hemodynamics, myocardial metabolism, and cardiac work efficiency were evaluated in five patients with bradycardia. The results were compared to those obtained in six normal subjects at rest. In order to elucidate the effects of a relatively high rate of ventricular pacing, cardiovascular and metabolic variables were also obtained at 120 bpm in the normal subjects. It was observed that the patients eventually benefited from ventricular pacing at a rate of 70 bpm and improved in systemic hemodynamics. Although coronary hemodynamics and myocardial metabolism were accelerated, the cardiac work efficiency was not improved. A pacing rate of 120 bpm in the normal subjects did not appear to accelerate systemic hemodynamics, but adverse accelerations of coronary hemodynamics and myocardial metabolism were observed, and the cardiac work efficiency was remarkably reduced as a result. Our observations indicated that the coronary reserve capacity was very important for ventricular pacing, and suggested that an undue increment of the pacing rate not only might be meaningless but also might induce ischemic angina. Therefore, we should be cautious in using a rate-responsive pacing mode, particularly in determination of the upper limit of pacing rates, although many benefits with this pacing mode have recently been advocated.

**KEYWORDS:** ventricular pacing, rate-responsive, hemodynamics, myocardial metabolism, cardiac work efficiency

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# Influences of Ventricular Pacing on Hemodynamics, Myocardial Metabolism, and Cardiac Work Efficiency: Potential Risks of Rate-Responsive Ventricular Pacing

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**The influences of ventricular pacing at a rate of 70 beats/min (bpm) on the systemic and coronary hemodynamics, myocardial metabolism, and cardiac work efficiency were evaluated in five patients with bradycardia. The results were compared to those obtained in six normal subjects at rest. In order to elucidate the effects of a relatively high rate of ventricular pacing, cardiovascular and metabolic variables were also obtained at 120 bpm in the normal subjects. It was observed that the patients eventually benefited from ventricular pacing at a rate of 70 bpm and improved in systemic hemodynamics. Although coronary hemodynamics and myocardial metabolism were accelerated, the cardiac work efficiency was not improved. A pacing rate of 120 bpm in the normal subjects did not appear to accelerate systemic hemodynamics, but adverse accelerations of coronary hemodynamics and myocardial metabolism were observed, and the cardiac work efficiency was remarkably reduced as a result. Our observations indicated that the coronary reserve capacity was very important for ventricular pacing, and suggested that an undue increment of the pacing rate not only might be meaningless but also might induce ischemic angina. Therefore, we should be cautious in using a rate-responsive pacing mode, particularly in determination of the upper limit of pacing rates, although many benefits with this pacing mode have recently been advocated.**

*Key words :* ventricular pacing, rate-responsive, hemodynamics, myocardial metabolism, cardiac work efficiency

Recent advancements in cardiac pacing techniques are remarkable. Numerous papers have reported the superiority of atrial synchronized ventricular pacing to conventional fixed rate (VVI) pacing with regard to hemodynamics, subjective feelings, and exercise capacity (1, 2). In patients with sinus node disease, however, the right atrial rate cannot be an indicator of circulatory demand. As a consequence, a variety of sensors have been developed and utilized for rate-responsive ventricular (VVI-R) pacing to detect the need for an increased heart rate (3-6). There are also many papers describing the superiority of VVI-R pacing to VVI pacing (2, 3, 7,

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8), encouraging the present trend to prefer the activity-sensing pacemaker which is simple, and easy to implant and program. Adverse side effects of ventricular pacing, whether or not they may be rate-responsive, are of most concern (9–11). Because, there are only a few papers describing the influences of ventricular pacing on coronary hemodynamics (7, 11), myocardial metabolism (7, 10), and cardiac work efficiency (7, 10). We focused our study on these, and also tried to elucidate potential risks of VVI-R pacing.

## Subjects and Methods

*Patients with bradycardia (brady-group).* Basal clinical characteristics of the five patients with bradycardia, who were the subjects in this study, are presented in Table 1. All patients underwent a routine electrophysiological study and diagnostic catheterization, including coronary angiography and left ventriculography. Patients were strictly excluded from the study when they had other cardiac disorders. After completion of the conventional catheterization study, a Wilton Webster coronary thermodilution catheter (Webster Labs. Altadena, California, USA) was inserted in the coronary sinus through the left antecubital vein for determination of coronary sinus blood flow (CSF, and CSFI as index) (13). A temporary endocardial ventricular pacing catheter, an Edwards Swan-Ganz cardiac output thermodilution catheter (Baxter Healthcare Corp., Irvine, California, USA), that were inserted through the right femoral vein, and a pigtail catheter inserted through a femoral artery and advanced into the left ventricle, were used for pacing, measurements of cardiac output (CO, and CI as index) and blood pressures, and for blood samplings as appropriately as needed.

*Normal subjects (normal group).* Six normal candidates were also subjected to the study (Table 1). They underwent routine cardiac and coronary catheterization studies because of a complaint of angina-like symptoms, but were found to be free from any cardiac and coronary lesion. All study preparations were completed in the same way as in the brady-group.

Details of the study, including possible complications, were thoroughly explained to patients, and the written permission was obtained from all patients in both groups.

*Measurements.* When the patients were on their own HR (non-paced phase), parameters listed below were measured in both groups. These parameters were also measured during ventricular pacing (paced phase) at a rate of 70 beats/min (bpm) in the brady-group and at a rate of 120 bpm in the normal group for longer than five minutes for each.

*Systemic hemodynamic variables.* HR (bpm), aortic systolic, diastolic and mean pressures (mm Hg), left ventricular end-diastolic pressure (LVEDP; mm Hg), CI ($l/min/m^2$), stroke volume index (SVI; $ml/beat/m^2$), left ventricular minute-work (LVWI; $kg \cdot m/min/m^2$), which was calculated as: LVWI = CI x (mAP-LVEDP) x 0.0136, where mAP = mean aortic pressure.

*Coronary hemodynamic variables.* CSFI ($ml/min/m^2$), coronary vascular resistance (CVRI; $mm\ Hg/ml/min/m^2$), which was calculated as: CVRI = (mAP-RAP)/CSFI, where RAP = right atrial mean pressure.

*Myocardial metabolic variables.* Myocardial oxygen consumption ($M\dot{V}O_2$; $ml/min/m^2$), which was calculated as: $M\dot{V}O_2 = C\ (a\text{-}cs)\ O_2 \times CSFI/100$, where C (a-cs) $O_2$ = aortocoronary sinus oxygen content difference. Myocardial lactate extraction (L-Ext; $mg/min/m^2$), which was calculated as: L-Ext = C (a-cs) L x CSFI/100, where C(a-cs) L = aortocoronary sinus lactate concentration difference.

*Efficiency of cardiac work.* Efficiency of cardiac work represented by the left ventricular (LV) work was evaluated using indices of $LVWI/M\dot{V}O_2$ ($kg \cdot m/ml$) and LVWI/L-Ext ($kg \cdot m/mg$).

*Statistic analysis.* All values are expressed as mean ± SD. Paired Student's *t*-tests were used to evaluate the changes in the same group, and an unpaired Student's *t*-test was applied for comparing the values in the two groups. A value of $p < 0.05$ was considered statistically significant.

## Results

The study process was completed without any complication, though in one case (subject No. 2 in the normal group) the tip of a Webster catheter dislodged from coronary sinus during pacing, and could not be replaced after that. Data on the paced phase are unavailable in this case.

The results of systemic hemodynamics in both groups are compared in Table 2-a and b. The non-paced HR in the brady-group was

significantly lower than that in the normal group (Table 1), and increased significantly ($p < 0.01$) as to be 70 bpm by pacing in all cases. In the normal group, HR was also increased significantly ($p < 0.01$) from the basal value to 120 bpm by pacing in all cases. The aortic systolic pressure at the non-paced phase was significantly ($p < 0.01$) from the baseline value to but this difference disappeared at the paced phase. There was no significant change by pacing in each group. Nor was there any remarkable difference in the aortic diastolic and mean pressures, and the LVEDP among the groups and phases. CI in the non-paced brady-group was significantly smaller than that in the non-paced normal group, but it was increased by pacing and the difference disappeared, whereas, in the normal group, an increase in CI by pacing was not obtained at all (Table 2-b). Initially, there was no difference between the non-paced SVIs of the two groups. With pacing, however, SVI decreased in both groups; this was significant in the normal group. The non-paced LVWI was significantly smaller in the brady-group than in the normal group, but it increased significantly by pacing in the brady-group, while it did not in the normal group. Consequently, the difference between the groups observed at the non-paced phase disappeared at the paced phase (Table 2-b).

The results for coronary hemodynamics in both groups are presented in Table 3. CSFI had already increased significantly at the non-paced phase in the brady-group as compared to that in the normal group. It further increased during pacing in both groups; this change was statistically significant in the normal group. The non-paced CVRI was significantly lower in the brady-group than in the normal group. The CVRI further decreased by pacing in both groups, and this difference was significant in the normal group, resulting in disappearance of the difference observed between the groups at the non-paced phase.

Results of the measurements of myocardial motabolism are summarized in Table 4. There was no significant difference in $M\dot{V}O_2$ between

**Table 1** Clinical characteristics

| | Age (years) | Sex | Heart rate (bpm) | Underlying diseases |
|---|---|---|---|---|
| Normal group[a] | | | | |
| Subject no. | | | | |
| 1 | 51 | Female | 61 | — |
| 2 | 51 | Female | 56 | — |
| 3 | 53 | Female | 56 | — |
| 4 | 28 | Male | 73 | — |
| 5 | 61 | Female | 67 | — |
| 6 | 67 | Male | 68 | — |
| Mean±SD | 51.8±13.3 | | 63.5±7.0 | |
| Brady-group | | | | |
| Subject no. | | | | |
| 1 | 72 | Female | 45 | C-AV block |
| 2 | 64 | Male | 45 | Af with brady. |
| 3 | 78 | Female | 40 | C-AV block |
| 4 | 53 | Male | 50 | SSS (Type 2[b]) |
| 5 | 79 | Male | 38 | C-AV block |
| Mean±SD | 69.2±10.8[c] | | 43.6±4.7[c] | |

bpm: beat/min; Brady-group: Bradycardia group; C-AV; Complete atrioventricular; Af: Atrial fibrillation: brady.: bradycardia; SSS: Sick sinus syndrome.

*a*: Angina pectoris was suspected of, but all subjects were diagnosed as not having any cardiac or coronary lesion.

*b*: Rubenstein's classification (12)

*c*: $p < 0.01$, compared to each corresponding value in the normal group.

**Table 2-a** Results of systemic hemodynamics

| | Aortic pressure (mm Hg) | | | | | | LVEDP (mm Hg) | |
|---|---|---|---|---|---|---|---|---|
| | Systolic | | Diastolic | | Mean | | | |
| | N-paced | Paced | N-paced | Paced | N-paced | Paced | N-paced | Paced |
| Normal group[a] | | | | | | | | |
| Subject no. | | | | | | | | |
| 1 | 132 | 122 | 65 | 75 | 96 | 90 | 7 | 6 |
| 2 | 150 | 158 | 82 | 100 | 103 | 120 | 8 | 6 |
| 3 | 116 | 120 | 62 | 56 | 80 | 82 | 5 | 5 |
| 4 | 120 | 122 | 81 | 85 | 95 | 100 | 6 | 6 |
| 5 | 128 | 152 | 70 | 92 | 89 | 111 | 5 | 4 |
| 6 | 124 | 128 | 78 | 80 | 92 | 93 | 6 | 6 |
| Mean±SD | 128.3±12.0 | 133.7±16.8 | 73.0±8.5 | 81.3±15.2 | 92.5±7.7 | 99.3±14.1 | 6.2±1.2 | 5.5±0.8 |
| Brady-group | | | | | | | | |
| Subject no. | | | | | | | | |
| 1 | 148 | 138 | 65 | 60 | 85 | 80 | 6 | 4 |
| 2 | 136 | 140 | 40 | 52 | 64 | 69 | 14 | 12 |
| 3 | 170 | 205 | 54 | 72 | 80 | 105 | 6 | 5 |
| 4 | 158 | 164 | 84 | 86 | 109 | 112 | 5 | 6 |
| 5 | 154 | 117 | 72 | 60 | 99 | 79 | 8 | 5 |
| Mean±SD | 153.2±12.5* | 152.8±33.6 | 63.0±16.6 | 66.0±13.3 | 87.4±17.4 | 91.0±17.8 | 7.8±3.6 | 6.4±3.2 |

LVEDP: Left ventricular end-diastolic pressure; N-paced: Non-paced phase; Paced: Paced phase; Other abbreviations are the same as in Table 1. *: $p < 0.01$, compared to the corresponding value in the normal group. *a*: See Table 1.

**Table 2-b** Results of systemic hemodynamics

| | CI (1/min/m$^2$) | | SVI (ml/beat/m$^2$) | | LVWI (kg・m/min/m$^2$) | |
|---|---|---|---|---|---|---|
| | N-paced | Paced | N-paced | Paced | N-paced | Paced |
| Normal group[a] | | | | | | |
| Subject no. | | | | | | |
| 1 | 3.83 | 3.45 | 62.8 | 28.7 | 4.61 | 3.89 |
| 2 | 5.23 | 4.83 | 93.5 | 40.3 | 6.76 | 7.49 |
| 3 | 6.64 | 5.27 | 118.0 | 43.9 | 6.77 | 5.52 |
| 4 | 4.00 | 3.40 | 54.8 | 28.3 | 4.84 | 4.35 |
| 5 | 2.86 | 2.98 | 42.8 | 24.8 | 4.56 | 4.51 |
| 6 | 3.25 | 3.81 | 47.8 | 31.8 | 3.80 | 4.50 |
| Mean±SD | 4.30±1.40 | 3.96±0.90 | 69.9±29.6 | 33.0±7.5[b] | 5.22±1.24 | 4.86±1.29 |
| Brady-group | | | | | | |
| Subject no. | | | | | | |
| 1 | 3.58 | 3.94 | 80.1 | 54.7 | 3.85 | 4.07 |
| 2 | 1.82 | 3.07 | 40.6 | 43.8 | 1.30 | 2.38 |
| 3 | 2.48 | 3.16 | 62.1 | 44.8 | 2.50 | 4.30 |
| 4 | 3.30 | 4.38 | 66.9 | 62.2 | 4.66 | 6.31 |
| 5 | 2.84 | 3.67 | 74.6 | 52.4 | 3.51 | 3.64 |
| Mean±SD | 2.81±0.70[b] | 3.64±0.55[c] | 64.9±15.2 | 51.6±7.6 | 3.16±1.30[d] | 4.14±1.42[c] |

CI: Cardiac index; SVI: Stroke volume index; LVWI: Left ventricular minute-work index. Other abbreviations are the same as in Tables 1 and 2-a.
*a*: See Table 1. *b*: $p < 0.01$, compared to each value at N-paced phase in the normal group. *c*: $p < 0.05$, compared to the value at N-paced phase in the same group. *d*: $p < 0.05$, compared to the value at N-paced phase in the normal group.

**Table 3** Coronary hemodynamics

| | CSFI (ml/min/m²) | | CVRI (mm Hg/ml/min/m²) | |
|---|---|---|---|---|
| | N-paced | Paced | N-paced | Paced |
| Normal group[a] | | | | |
| Subject no. | | | | |
| 1 | 72.0 | 128.0 | 1.29 | 0.66 |
| 2 | 50.0 | — | 2.79 | — |
| 3 | 46.2 | 80.8 | 1.56 | 0.98 |
| 4 | 26.6 | 69.1 | 3.38 | 1.38 |
| 5 | 51.6 | 76.1 | 1.72 | 1.09 |
| 6 | 52.3 | 84.8 | 1.76 | 1.10 |
| Mean±SD | 49.8±14.5 | 87.8±23.2[b] | 2.08±0.81 | 1.04±0.26[b] |
| Brady-group | | | | |
| Subject no. | | | | |
| 1 | 101.4 | 117.0 | 0.84 | 0.68 |
| 2 | 150.0 | 167.9 | 0.47 | 0.45 |
| 3 | 65.4 | 84.6 | 1.23 | 1.24 |
| 4 | 64.4 | 141.1 | 1.70 | 0.79 |
| 5 | 76.9 | 215.4 | 1.29 | 0.37 |
| Mean±SD | 91.6±35.9[b] | 145.2±49.8[c] | 1.10±0.47[b] | 0.71±0.34[c] |

CSFI: Coronary sinus flow index; CVRI: Coronary vascular resistance index.
Other abbreviations are the same as in Tables 1 and 2-a. Variables at the paced phase in the subject no. 2 in the normal group were not obtained (See in the text).
*a*: See Table 1. *b*: $p < 0.05$, *c*: $p < 0.01$, compared to each value at N-paced phase in the normal group.

**Table 4** Myocardial metabolism

| | $M\dot{V}O_2$ (ml/min/m²) | | L-Ext (mg/min/m²) | |
|---|---|---|---|---|
| | N-paced | Paced | N-paced | Paced |
| Normal group[a] | | | | |
| Subject no. | | | | |
| 1 | 5.7 | 12.9 | 1.9 | 2.7 |
| 2 | 3.8 | — | 1.7 | — |
| 3 | 3.9 | 6.9 | 2.2 | 2.1 |
| 4 | 3.4 | 8.4 | 1.3 | 3.3 |
| 5 | 5.9 | 9.0 | 1.8 | 2.2 |
| 6 | 4.5 | 7.7 | 1.6 | 3.0 |
| Mean±SD | 4.5±1.0 | 9.0±2.3[b] | 1.7±0.3 | 2.7±0.5[b] |
| Brady-group | | | | |
| Subject no. | | | | |
| 1 | 8.0 | 8.8 | 1.4 | 2.5 |
| 2 | 13.5 | 14.6 | 4.0 | 6.1 |
| 3 | 4.0 | 5.3 | 0.8 | 1.0 |
| 4 | 8.6 | 20.1 | 2.0 | 5.6 |
| 5 | 6.8 | 16.8 | 0.4 | 1.1 |
| Mean±SD | 8.2±3.5 | 13.1±6.0[b] | 1.7±1.4 | 3.1±2.6 |

$M\dot{V}O_2$: Myocardial oxygen consumption; L-Ext: Myocardial lactate extraction.
Other abbreviations are the same as in Tables 1 and 2-a. Variables at the paced phase in the subject no. 2 in the normal group were not obtained (See in the text).
*a*: See Table 1. *b*: $p < 0.05$, compared to each value at N-paced phase in the normal group.

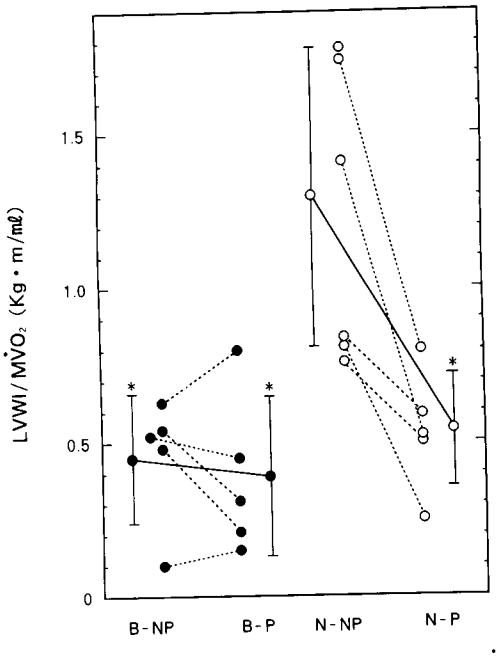


**Fig. 1** Cardiac work efficiency evaluated with LVWI/$M\dot{V}O_2$ before and during ventricular pacing at a rate of 70 bpm in the bradycardia group (●), and at a rate of 120 bpm in the normal group (○). The value in the bradycardia group at the non-paced phase (B-NP) is significantly smaller than that in the normal group at the same phase (N-NP), and it can not be increased by pacing (B-P), leaving the difference from the value at N-NP. While, the value at N-NP is significantly reduced at the pacing phase (N-P), and the difference between the groups has disappeared. In one case, the result could not be obtained at N-P. Values are presented as means with standard deviations indicated by brackets. *$P < 0.01$, compared to the value at N-NP.

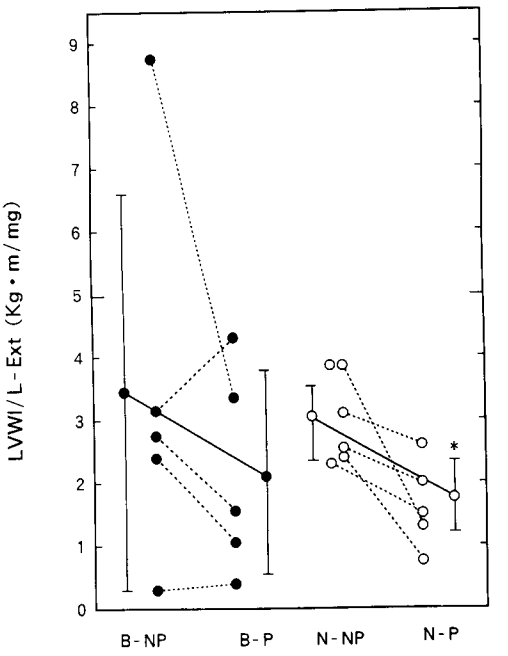


**Fig. 2** Cardiac work efficiency evaluated with LVWI / L-Ext before and during ventricular pacing. In the normal group, it is significantly reduced by ventricular pacing (*$p < 0.05$). There is no significant difference between the groups at any phase. In one case, result could not be obtained at N-P. Marks, expressions, and abbreviations are the same as in Fig. 1.

the groups at the same phase. $M\dot{V}O_2$ increased by pacing in both groups, but this was statistically significant in the normal group. The $M\dot{V}O_2$ at the paced phase in the brady-group, however, exceeded the value at the non-paced phase in the normal group; this was significant. No remarkable difference was observed with L-Ext between the groups at any phase, and it was observed to increase during pacing in both groups; this change was significant in the normal group.

The LVWI/$M\dot{V}O_2$ at the non-paced phase was significantly smaller in the brady-group than in the normal group ($0.45 \pm 0.21$ vs $1.23 \pm 0.48$kg・m/ml; $p < 0.01$), and it could not be increased even by pacing, and the difference remained (Fig. 1). On the other hand, in the normal group, it was adversely reduced from $1.23 \pm 0.48$ to $0.54 \pm 0.18$kg・m/ml by pacing ($p < 0.05$). As a consequence, the difference between the groups observed at the non-paced phase disappeared. There was no significant difference with LVWI/L-Ext between the groups at any phase either. The LVWI/L-Ext, however, was significantly reduced from $3.06 \pm 0.69$ to $1.79 \pm 0.54$kg・m/mg by pacing in the normal group ($p < 0.01$; Fig. 2).

## Discussion

The thermodilution technique was used to determine CSF in the present study. This technique has been widely used in human subjects (7, 13, 14). The technique is reputed to be easy to

perform, having a high reproducibility of measurements and a close correlation with electromagnetic flow meter measurements (13, 15). The most important point with this technique is to keep the catheter tip at precisely the same site where it was initially placed in the coronary sinus to achieve reproducibility. So, we took meticulous care on this point, and kept the tip continuously placed in the coronary sinus throughout the evaluation process. In one case, however, the catheter tip dislodged and reinsertion was impossible as described.

In respect to coronary venous system, it has been documented that coronary sinus drained little from the right coronary artery and drained approximately 50 % of the left coronary artery supply (16). Thus, the CSF does not accurately indicate the real coronary artery blood flow. We, however, considered that CSF would reflect the characteristics of coronary hemodynamics in terms of ventricular pacing in cases without significant coronary artery stenoses. Therefore, we used CSF as an indicator of coronary hemodynamics (12, 13, 15). The evaluation of myocardial metabolism was possible by measuring the contents of substrates in coronary arterial and coronary sinus blood, although this might not reflect the metabolism of a whole heart.

We compared variables in patients with bradycardia at the paced and non-paced phases to those of the normal subjects at rest to know how the patients could be benefited by ventricular pacing. Furthermore, we compared the variables with ventricular pacing at a rate of 70 bpm to those at a rate of 120 bpm in order to assess possible benefits and risks of the increased rate. We considered that this comparison was justified, because the contribution of the atrioventricular synchrony was equally eliminated in both groups. An improved study design might include the comparison between the variables obtained at the pacing rates of 70 bpm and 120 bpm in the same brady-group to correctly evaluate the effect of an increase in the pacing rate. Results of future studies should corroborate our observations.

The reasoning for setting the pacing rate at 70 bpm in the brady-group and 120 bpm in the normal group is as follows. The rate of 70 bpm has been most commonly used for clinical VVI pacing. And, the upper limitation of an increase in the HR by VVI-R pacing has been programmed most commonly as to be 120 bpm.

There are many papers describing hemodynamic affects of VVI pacing, but the results are still controversial (1-3, 7-11). In the present study, increases in CO and LVWI with ventricular pacing at a rate of 70 bpm were observed, in agreement with our previous and others' results (17, 18). On the contrary, however, such an increase could not be obtained with the rate of 120 bpm. Baucher *et al.* have reported a similar observation (19).

Influences of cardiac pacing on coronary hemodynamics and myocardial metabolism have been little studied in clinical cases (7, 10, 11, 20). Dhainaut *et al.* (14) cited that "Under physiological condition, changes in coronary blood flow are in proportion to the myocardial oxygen demand and the rate of myocardial oxygen consumption is closely related to the work performed". Our observation, however, was that CSF significantly increased at the non-paced phase in the brady-group in spite of a smaller LVWI as compared to that in the normal group at the same phase. Additionally, CVRI significantly decreased at the non-paced phase in the brady-group. As shown with $M\dot{V}O_2$, myocardial metabolism was already accelerated, though not significantly, at the non-paced phase in this group, also. There was a trend that coronary hemodynamics and myocardial metabolism were further accelerated by ventricular pacing, and the acceleration was statistically significant at the rate of 120 bpm. Thus, in the present study, correlation between the aortic pressure and $M\dot{V}O_2$ was not observed, although tension-time index was generally considered to correlate well with $M\dot{V}O_2$. Besides, $M\dot{V}O_2$ at the paced phase in the brady-group was significantly larger than that in the non-paced normal group, though there was

neither a significant difference among the corresponding aortic pressures nor among the corresponding HRs. It was reported that abnormality of the LV regional wall motion increased $M\dot{V}O_2$ and reduced LV work efficiency (21). Such the regional wall motion abnormality was usually observed in cases with LV pacing (19). In this study, however, the influence of the differences in the systemic blood pressures, heart sizes, and HRs on CVRI and $M\dot{V}O_2$ was not sufficiently elucidated. This problem should be further investigated.

It was observed that the cardiac work efficiency could not significantly be improved by pacing in the brady-group, even though CI and LVWI statistically increased. This was because we thought that the degree of hemodynamic improvement by pacing was underproportional to the coronary hemodynamic and metabolic acclerations. Moreover, by pacing at the rate of 120 bpm, the cardiac work efficiency was markedly and adversely reduced. Consequently, we could not help thinking that the accelerations of coronary hemodynamics and myocardial metabolism were only for the heart to contract in a forced way by the pacemaker stimulations even when the stimulation rate might not be reasonable one, and that the increase in the pacing rate in such a way was quite meaningless. This gap between the HR pace and physiological need may easily take place with rate-responsive pacemakers, particularly with activity-responsive one, since the activity signal is not a physiological one as a sensor.

Another important implication of the present results was that the ventricular pacing therapy was supported by coronary reserve capacity. Accordingly, an undue increment of ventricular pacing rates may cause myocardial ischemia as observed as pacemaker-induced angina when significant coronary artery-stenoses are associated (15, 20). This problem should be made clear in the near future.

Our observations do not negate the advantages of VVI-R pacing. They do indicate the importance of a prudent attitude in utilization of rate-responsive pacemakers, knowing that an undue increment of pacing rates neither benefit patients nor improve cardiac work efficiency. The present study was too small to draw a definitive conclusion. Further studies of this kind with a large number of subjects will be necessary.

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