The Influence of Ventricular Extrasystoles and Postextrasystoles on Cardiovascular Dynamics in Anesthetized Dogs

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The influence of ventricular extrasystoles and postextrasystoles on cardiovascular dynamics were assessed in terms of maximum rate of rise of left ventricualr pressure (max dP/dt), ascending aortic flow, left ventricular stroke volume, and left ventricular end-diastolic transverse dimension in anesthetized dogs. A single ventricular extrasystole, two and three consecutive ventricular extrasystoles (couplet and triplet) were induced by applying mechanical stimulation to the surface of the right ventricule.

In any of these ventricular extrasystoles, max dP/dt, stroke volume and end-diastolic transverse dimension were decreased, compared with those in preceding sinus beats, i.e., pre-extrasystoles. Over the several postextrasystoles, max dP/dt was increased and gradually returned to its control level. This increase in max dP/dt, i.e., postextrasystolic potentiation paralleled an increase in ascending aortic peak flow but did not always bring about an increase in stroke volume, even when a left ventricular contraction was initiated by a significantly greater end-diastolic transverse dimension. The postextrasystolic potentiation seems to be associated with the Frank-Starling mechanism and does not compensate for the decrease in stroke volume elicited by the ventricular extrasystoles. In conclusion, not only ventricular extrasystoles per se but also postextrasystoles exert the advarse influence on cardiovascular dynamics consecutively. (Key words: ventricular extrasystoles, postextrasystoles, postextrasystolic potentiation, cardiovascular dynamics)

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Runs of ectopic tachycardia commonly lead to some degree of hemodynamic embarrassment, i.e., a decrease in stroke volume, blood pressure, or cardiac output[1–4]. Although the influence of tachydysrhythmias on selected aspects of cardiac performance has been investigated[1–4], the quantitative effects of ventricular extrasystoles and following postextrasystolic sinus beats, i.e., postextrasystoles on stroke volume and cardiac output remain unclear.

Ventricular extrasystoles condition the myocardium in such a way that the next succeeding contraction is stronger than the preceding normal contraction. This phenomenon is referred to as postextrasystolic potentiation.

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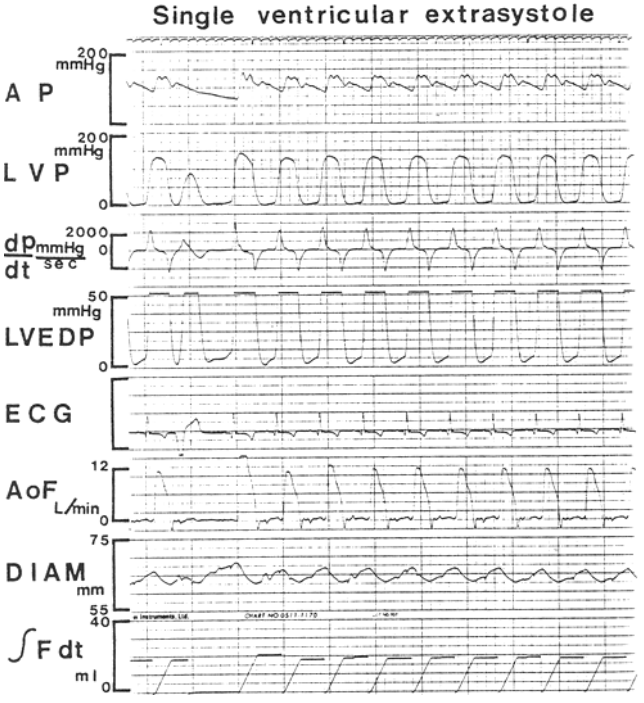

Fig. 1. Simultaneous recording of hemodynamic variables during a pre-extrasystole, a single ventricular extrasystole and postextrasystoles.

AP = arterial pressure; LVP = left ventricular pressure; dP/dt = first derivative of LVP with time; LVEDP = left ventricular end-diastolic pressure; ECG = electrocardiogram (lead II); AoF = ascending aortic flow; DIAM = left ventricular transverse diameter (dimension); $\int$Fdt = stroke volume (SV)

A typical single ventricular extrasystole is shown in the fifth tracing from above.

This single ventricular extrasystole decreased max dP/dt and end-diastolic DIAM (EDD). AoF and SV did not appear in this extrasystole. The first postextrasystole increased max dP/dt, AoF and SV, and was initiated by a greater EDD.

Especially unknown are the quantitative effects of two and three consecutive extrasystoles (couplet and triplet) or postextrasystoles on cardiovascular dynamics. This study was therefore undertaken to explore the influence of a single ventricular extrasystole, couplet, triplet or the following postextrasystoles on cardiovascular dynamics.

Methods

Twenty dogs, weighing between 15 and 23 kg, were studied.

Anesthesia was induced by intravenous pentobarbital (30 mg/kg). The trachea was intubated orally with a cuffed endotracheal tube without the use of muscle relaxants. Ventilation was controlled with a volume-limited animal ventilator (Acoma Animal Respirator) at tidal volumes of 25–30 ml/kg. Anesthesia was maintained by 5–2.5% sevoflurane in pure oxygen. The pharyngeal temperature was maintained between 35.2 and 37.4°C. Lactated Ringer solution was infused at a rate of 15–20 ml/kg/h through a femoral vein catheter.

Heart rate and rhythm from lead II of the electrocardiogram (ECG) were continuously monitored.

The chest was opened through the left fourth intercostal space. An appropriately sized electromagnetic flow plobe (FB-140T, NIHON KOHDEN) was placed around the ascending aorta and connected to a flowmeter (MFV2100, NIHON KOHDEN) for the measurement of ascending aortic flow (AoF). Stroke volume (SV) was obtained by integrating the ascending aortic flow. A micromanometer- tipped catheter (8F PC 380, Miller Instruments, Inc.) was inserted into the left ventricular cavity through the apex for the measurement of left ventricular pressure (LVP) and left ventricular end-diastolic pressure (LVEDP). First derivative of LVP with time (dP/dt) was obtained with an analog differentiating circuit (Contractility Unit 1323, NEC-Sanei Instr., Ltd.). Left ventricular transverse dimension was recorded continuously by measuring the transit time of ultrasound waves between two crystals mounted on opposite sides of the left ventricule (DIMENSION 4105 NEC-Sanei Instr., Ltd.). The external left ven-

tricular end-diastolic transverse dimension (EDD) was measured at the onset of the QRS. A rigid polyethylene catheter was inserted through the left internal carotid artery for arterial pressure (AP) monitoring. This catheter was also used for arterial blood sampling. At the completion of surgical preparation, the sevoflurane-inspired concentration was adjusted to 2.5% and thirty minutes were allowed for stabilizing hemodynamics. During this stabilization period, all measuring devices were recalibrated. Arterial blood-gas tensions and pH were analyzed, and ventilation was adjusted to normocarbia, and sodium bicarbonate was given according to the base deficit.

The selected ventricular extrasystoles were induced by applying mechanical stimulation to the surface of the right ventricle. Atrial extrasystoles and all the ventricular extrasystoles with artifacts were excluded from this study. A single ventricular extrasystole, couplet or triplet, and the following postextrasystoles occurring in a basal condition were investigated. The requirements for basal condition were twenty regular sinus beats before and after the ventricular extrasystoles. Hemodynamic variables were continuously recorded on a polygraph (RECTI-HORIZ-8K23, NEC-Sanei, Instr., Ltd.). Maximum dP/dt (max dP/dt), AoF, SV and EDD were measured during pre-extrasystole, extrasystoles and four consecutive postextrasystoles.

In regard to max dP/dt and SV, percent changes were determined by taking those in the pre-extrasystole as reference. All results were presented as means ± SE. In regard to EDD, the results were presented as means ± SE of absolute values.

Statistical analyses were made by using paired Student's t test. $P<0.05$ was considered significant.

Results

Single Ventricular Extrasystole

A typical example is shown in figure 1.

Percent changes in max dP/dt and stroke volume are shown in figure 2. The single ventricular extrasystole significantly decreased max dP/dt by 66 ± 3% and stroke volume by 96 ± 3%. The first, second, third and fourth postextrasystoles significantly increased max dP/dt by 46 ± 3%, 12 ± 3%, 15± 2%, and 7 ± 1% respectively. This increase in max dP/dt paralleled an increase in ascending aortic peak flow. The first and third postextrasystoles significantly increased stroke volume by 7 ± 2% and 2 ± 1% respectively. The second and fourth postextrasystoles did not increase stroke volume.

The single ventricular extrasystole was

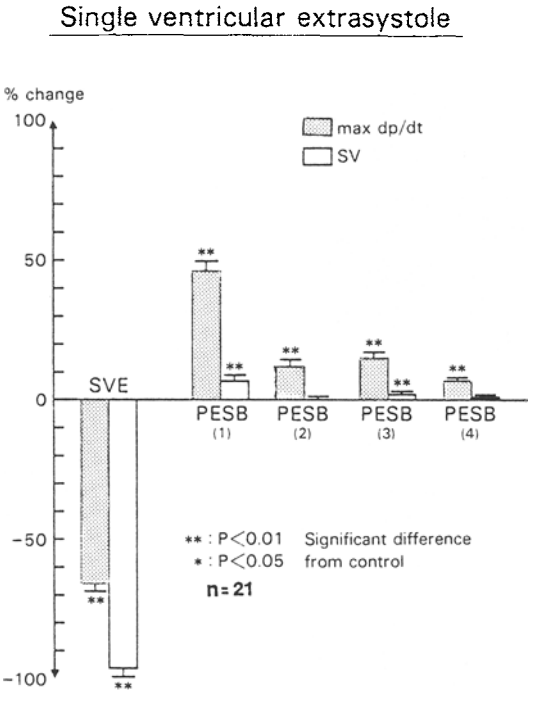

Fig. 2. The percent change of max dP/dt and stroke volume during both the single ventricular extrasystole (n = 21) and the following four postextrasystoles. For each bar, the vertical line denotes a standard error from the mean.

SVE = single ventricular extrasystole; PESB (post extrasystolic beat) (1) = first post extrasystole; PESB(2) = second postextrasystole; PESB(3) = third postextrasystole; PESB(4) = fourth postextrasystole.

The single ventricular extrasystole significantly decreased max dP/dt and SV.

Each of four postextrasystoles significantly increased max dP/dt. The first and third postextrasystoles significantly increased SV. The second and fourth postextrasystoles did not increase SV.

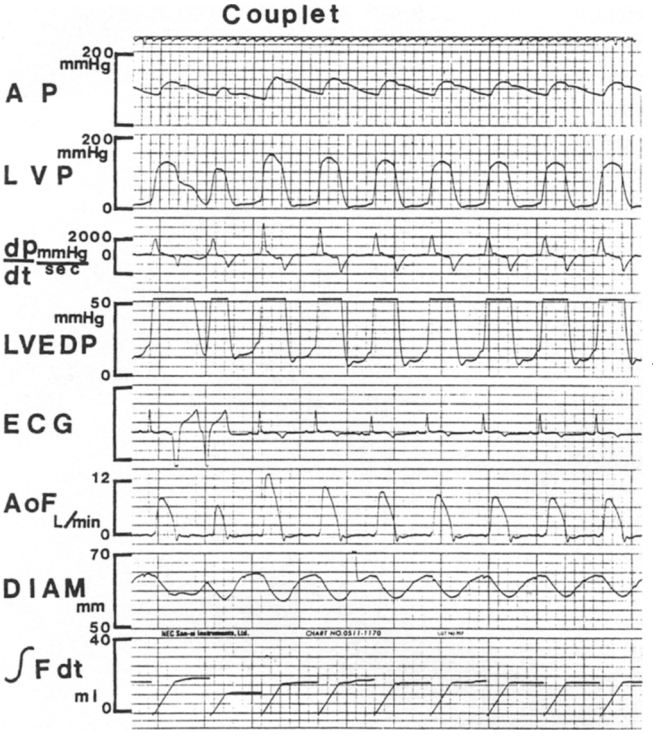

Fig. 3. Simultaneous recording of hemodynamic variables during a pre-extrasystole, a couplet and postextrasystoles.

Abbreviations are the same as in figure 1.

A typical couplet is shown in the fifth tracing from above. In this couplet, only the first extrasystole decreased max dP/dt and EDD. AoF and SV did not appear in this.

The second extrasystole of this couplet decreased EDD, AoF and SV.

Over the several postextrasystoles, peak AoF was increased in parallel with an increase in max dP/dt.

initiated by a significantly smaller end-diastolic dimension than that in the pre-extrasystole (fig. 7).

The first postextrasystole was initiated by a significantly greater end-diastolic dimension (fig. 7). The second and third post-extrasystoles were initiated by the almost same end-diastolic dimensions as those in pre-extrasystoles (fig. 7). The R-R intervals remained unchanged during both pre-extrasystoles and postextrasystoles.

Couplet

A typical example is shown in figure 3.

Percent changes in max dP/dt and stroke volume are shown in figure 4. The first extrasystole of the couplet significantly decreased max dP/dt by 57 ± 7%. The second extrasystole of the couplet showed a tendency to decrease max dP/dt. The first and second extrasystoles of the couplet significantly decreased stroke volume by 70 ± 8% and 61 ± 8% respectively.

The first, second, third, and fourth post-extrasystoles significantly increased max dP/dt by 67 ± 9%, 42 ± 9%, 31 ± 5% and 19 ± 5% respectively. The incrase in max dP/dt paralleled an increase in ascending aortic peak flow. Four postextrasystoles, however, showed a tendency to decrease stroke volume.

The couplet was initiated by significantly smaller end-diastolic dimensions (fig. 7). The first postextrasystole was initiated by a significantly greater end-diastolic dimension (fig. 7). The second and third post-extrasystoles were initiated by the almost same end-diastolic dimensions as those in pre-extrasystoles (fig. 7).

The R-R intervals remained unchanged during both pre-extrasystoles and postextrasystoles.

Triplet

A typical example is shown in figure 5.

Percent changes in max dP/dt and stroke volume are shown in figure 6. The first and second extrasystoles of the triplet significantly decreased max dP/dt by 71 ± 5% and 31 ± 10% respectively. The third extrasystole of the triplet showed a tendency to decrease max dP/dt. Each extrasystole

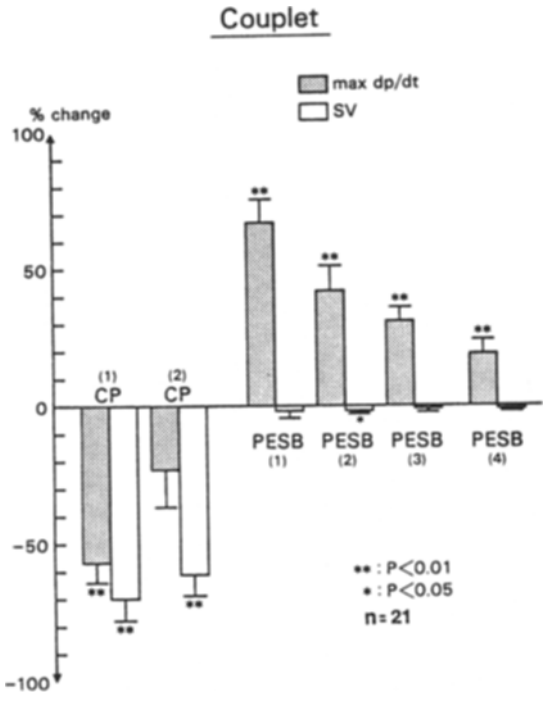

Fig. 4. The percent change of max dP/dt and stroke volume during both the couplet (n = 21) and the following four postextrasystoles. For each bar, the vertical line denotes a standard error from the mean. CP (couplet) (1) = first extrasystole of the couplet; CP(2) = second extrasystole of the couplet; Other abbreviations are the same as in figure 2.

The first extrasystole of the couplet significantly decreased max dP/dt. The second extrasystole of the couplet showed a tendency to decrease max dP/dt. The couplet significantly decreased SV.

Each of four postextrasystoles significantly increased max dP/dt but showed a tendency to decrease SV.

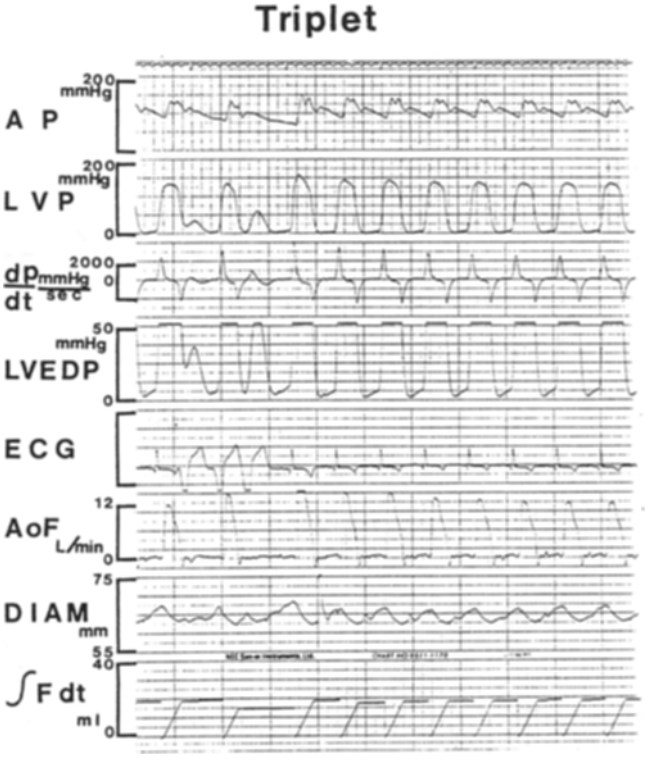

Fig. 5. Simultaneous recording of hemodynamic variables during a preextrasystole, a triplet and postextrasystoles. Abbreviations are the same as in figure 1.

A typical triplet is shown in the fifth tracing from above. Two decreased max dP/dts, one increased max dP/dt, one increased AoF, two decreased EDDs and one decreased SV appeared during this triplet. The second extrasystole of this triplet increased max dP/dt. This seems to be a postextrasystolic potentiation.

Over the several postextrasystoles, peak AoF was increased in parallel with an increase in max dP/dt. The first postextrasystole was initiated by a greater EDD but did not increase SV in spite of a marked increase in max dP/dt. The second and third postextrasystoles rather decreased SV and EDD. The fourth postextrasystoles also did not increase SV inspite of increase in max dP/dt.

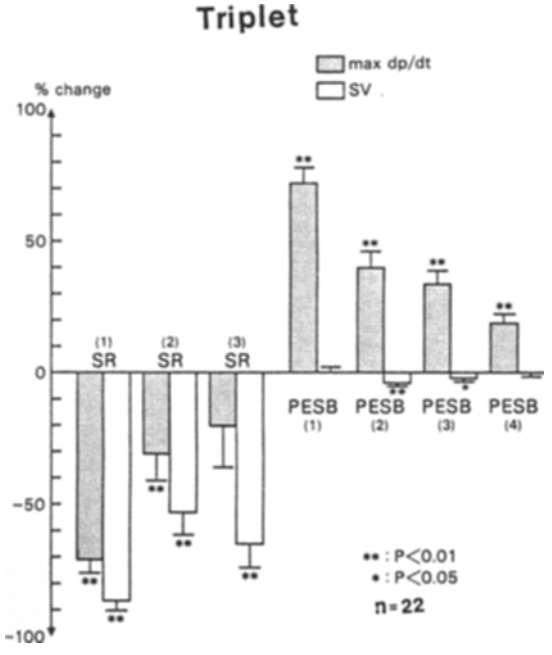

Fig. 6. The percent change of max dP/dt and stroke volume during both the triplet (n = 22) and the following four postextrasystoles. For each bar, the vertical line denotes a standard error from the mean. Sort run indicates triplet. SR (short run) (1) = first extrasystole of the triplet; SR(2) = second extrasystole of the triplet; SR(3) = third extrasystole of the triplet; Other abbreviations are the same as in figure 2.

The first and second extrasystoles of the triplet significantly decreased max dP/dt. The third extrasystole of the triplet showed a tendency to decrease max dP/dt. The triplet significantly decreased SV.

Each of four postextrasystoles significantly increased max dP/dt but did not increase SV. The second and third postextrasystoles rather decreased SV.

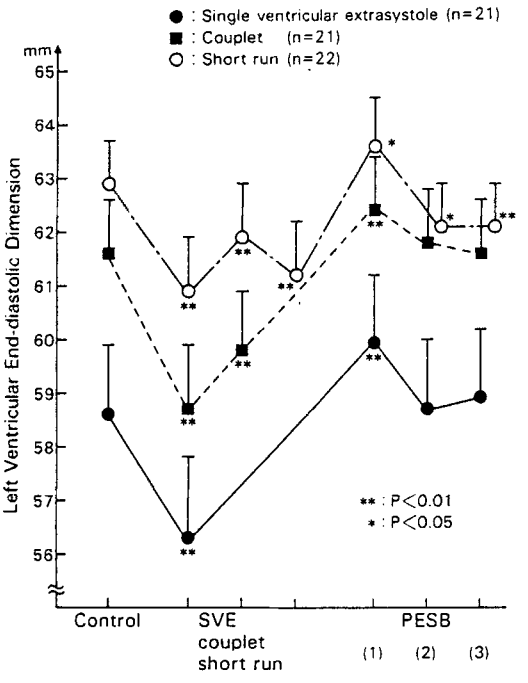

Fig. 7. Changes in the left ventricular end-diastolic transverse dimension during pre-extrasystoles, ventricular extrasystoles and postextrasystoles. The vertical line denotes a standard error from the mean. Short run indicates triplet. Abbreviations are the same as in figure 2.

The single ventricular extrasystole, couplet and triplet were initiated by significantly smaller end-diastolic dimensions than those in the pre-extrasystole.

The first postextrasystole following the single ventricular extrasystole, couplet and triplet was initiated by a significantly greater end-diastolic dimension. The second and third postextrasystoles following the triplet were initiated by significantly smaller end-diastolic dimensions.

of the triplet significantly decreased stroke volume by 86 ± 6%, 53 ± 9% and 65 ± 9% respectively.

The first, second, third, and fourth postextrasystoles significantly increased max dP/dt by 72 ± 6%, 40 ± 6%, 34 ± 5% and 19 ± 4% respectively. This increase in max dP/dt paralleled an increase in ascending aortic peak flow.

The second and third postextrasystoles decreased stroke volume by 4 ± 1% and 2 ± 1% respectively. However, the first and fourth postextrasystoles did not decrease stroke volume. The triplet was initiated by significantly smaller end-diastolic dimensions (fig. 7).

The first postextrasystole was initiated by a significantly greater end-diastolic dimension (fig. 7). The second and third postextrasystoles were initiated by significantly smaller end-diastolic dimensions (fig. 7).

The R-R intervals remained unchanged

during both pre-extrasystoles and postextrasystoles.

Discussion

In general, extrasystoles compromise the heart as a pump.

The factors considered to be potentially capable of influencing beat to beat left ventricular stroke volume and cardiac output include the degree of left ventricular filling which is in turn affected by presence or absence of preceding P waves, timing of the beat, transient appearance of aberration in ventricular activation, and the phenomenon of postextrasystolic potentiation[5]. In our study, the single ventricular extrasystole, couplet and triplet were initiated by significantly smaller end-diastolic dimensions, regarded as reflecting smaller left ventricular end-diastolic volume[6].

These extrasystoles, by virture of their infringement on diastolic filling, generated stroke volumes which were considerably lower than those in pre-extrasystoles.

It was demonstrated by Cohn and Kryda that the end-diastolic volume represents the principle determinant of beat to beat stroke volume, regardless of whether sinus rhythm, atrial fibrillation or atrial or ventricular extrasystoles were presents[5]. Thus, the Frank-Starling mechanism appears to take precedence over other variables as the prime mechanism governing hemodynamic changes during dysrhythmias[5]. That is, the close correlation between stroke volume and the end-diastolic volume preceding any given beat supports the concept that myocardial fiber length acts as the most potent beat to beat determinant of stroke volume[5]. Hence, earlier premature beats of variety of types are generally preceded by an incomplete degree of ventricular filling, and are thereby initiated by lower than usual end-diastolic volumes, the resultant stroke volume thus being diminished as well[5].

This does not conflict with our results seen in any type of ventricular extrasystoles.

The decrement in stroke volume brought about by any extrasystoles were greater than that in max dP/dt, which is often used as an index of myocardial contractility. Although changes in max dP/dt do not always reflect the changes in myocardial contractility which is independent of the Frank-Starling mechanism, our results indicate that end-diastolic volume may act as the more potent beat to beat determinant of stroke volume than myocardial contractility in any type of extrasystoles.

Our results in postextrasystoles conflicted with Cohn and Kryda's ones[5]. The first postextrasystole was always initiated by a significantly greater end-diastolic dimension. This seems to be due to blood pooling that was brought about by preceding extrasystoles. As seen in figure 2, 4 and 6, the increment in stroke volume was observed in the first postextrasystole following the single ventricular extrasystole, but not in the first postextrasystole following the couplet and triplet. Thus, the Frank-Starling mechanism dose not appear to take precedence over other variables as the prime mechanism governing the heart as a pump in the first postextrasystole following both the couplet and triplet.

Since 1885, it has been known that the heart beat following a premature contraction exhibits an increased contractile force. This "postextrasystolic potentiation" was considered initially to be explainable under the Frank-Starling mechanism. However, Hoffman, Bindler and Suckling showed that postextrasystolic potentiation is independent of the degree of muscle length, i.e., ventricular filling, studying this phenomenon in isolated, isometrically-contracting mammalian papillary muscles[7–9].

In our study, we used max dP/dt as an index of postextrasystolic potentiation. Postextrasystolic potentiations were consecutively observed over the several postextrasystoles following the single ventricular extrasystole, couplet or triplet. Each postextrasystolic potentiation was not followed by the increment in stroke volume except for the first and third ones following the single ventricular extrasystole. Contrarily, it is notable that the postextrasystolic potentiation was followed by the significant decrement in stroke vol-

ume following the couplet and triplet in spite of the unchanged R-R intervals. Judging from these findings, postextrasystolic potentiation may not always be associated with the Frank-Starling mechanism.

Why does the phenomenon of "postextrasystolic potentiation" occur? It is speculated that lower aortic end-diastolic pressure may cause stimulation of the carotid and aortic baroreceptors, which in turn would produce a higher elevation of max dP/dt[9]. However, this phenomenon is observed in isolated mammalian papillary muscles[7–9], as described above. Delineation of the mechanism of this phenomenon awaits further study. Postextrasystolic potentiation remains to be a fundamental characteristic of cardiac muscle, the magnitude of this potentiation being roughly proportionate to the degree of prematurity[5]. Anyway, the increment in stroke volume brought about by postextrasystoles was less than the decrement in stroke volume brought about by extrasystoles. Although the second and third postextrasystoles following the triplet were initiated by significantly smaller end-diastolic dimensions, these postextrasystoles increased max dP/dt. However, they did not bring about an increase in stroke volume. Thus, we believe that the postextrasystolic potentiation may not be effective enough to compensate for the lower stroke volume elicited by the extrasystoles and does not play an important role in augmenting stroke volume. In postextrasystolic potentiation, cardiac muscle may solely consume energy without the enhancement of cardiac pump function.

In fact, no one of postextrasystoles significantly increased stroke volume except for the first and third postextrasystoles following the single extrasystole. Also, we confirmed that mean ascending aortic flow which parallels cardiac output decreased during ventricular extrasystoles and returned to preextrasystolic level after four postextrasystoles or later.

The more severe the ventricular extrasystoles, the less the left ventricular filling, especially in second and third postextrasystoles, and subsequent blood pooling into the lung may occur.

In conclusion, not only ventricular extrasystoles per se but also postextrasystoles exert the adverse influence on cardiovascular dynamics consecutively. Namely, a marked decrease in stroke volume is brought about by ventricular extrasystoles, and an ineffective increase in myocardial contractility for the heart as a pump by postextrasystoles.

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