Increasing coronary perfusion pressure on diastolic and systolic performance is less pronounced in right ventricle than in left ventricle

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Abstract

Objectives: Little is known as to whether an increase in coronary perfusion pressure can alter the right ventricular (RV) distensibility and the contractile function as it does in the case of the LV. Methods: In eight isolated isovolumically contracting canine hearts, RV and LV volumes and coronary perfusion were independently controlled. Effects of an increase in coronary perfusion pressure (from 73 ± 1 to 152 ± 6 mmHg) on the end-diastolic and end-systolic pressure–volume relations in both RV and LV were assessed. Results: Following an increase in coronary perfusion, and at a similar volume of the ventricles, end-diastolic pressure was elevated by 2.8 ± 0.8 mmHg in RV and 8.9 ± 2.0 mmHg in LV (P < 0.01; RV vs LV), and the slope of RV end-systolic pressure–volume relation, Ees, increased by 11 ± 6% (P < 0.05) and that of the LV Ees by 21 ± 5% (P < 0.01). The percent change of RV pressure–volume area (PVA) was less than that in LV-PVA (26 ± 9 vs 48 ± 11%; P < 0.05). Conclusions: Accordingly, increases in coronary perfusion pressure and/or flow decreased the RV distensibility and enhanced the RV contractile function, the extent of which, however, was less than that in the LV.

Keywords: Coronary perfusion pressure; Gregg's phenomenon; Contractile function; Dog, anesthetized

1. Introduction

Increases in coronary perfusion pressure and/or blood flow cause a leftward shift of the left ventricular diastolic pressure–volume relation [1–4] along with an increase in the level of contractile state [5–10]. The reduction in diastolic distensibility following an increase in coronary perfusion pressure and flow has been termed an "erectile" effect, and the increased systolic pump performance and oxygen consumption termed Gregg's phenomenon. However, it has not been rigorously examined whether the increased coronary perfusion pressure alters the right ventricular pressure–volume relation as it does in the left ventricle.

Vascular density determined by arteriole, capillary, and venule inside the myocardium is similar in the right and left ventricles [11,12]. There are, however, several differences in the regulatory mechanism of coronary perfusion between the right and left coronary arteries. Extravascular compressive force is higher in the left than the right ventricular wall. Coronary blood flow per gram of the right ventricular myocardium is about two-thirds of that of the left ventricular myocardium [13–15], reflecting the differences in oxygen consumption of these ventricles. In addition to the differences in coronary circulation, not only the intracavity pressure but also the geometries including wall thickness, chamber shape and muscle mass are unique to the individual ventricles [16]. Accordingly, an increase in coronary perfusion may affect differently the diastolic and systolic ventricular performance of the right and left ventricles. To test this hypothesis, we used cross-circulated isolated canine hearts in which the right and left ventricular volumes as well as the level of coronary perfusion pressure were independently controllable.
2. Materials and methods

2.1. Preparations

The details for the anesthesia, controlled ventilation and surgical preparation have been previously described [17,18]. Briefly, 16 mongrel dogs were anesthetized with sodium pentobarbital (30 mg/kg i.v.) and were ventilated using a positive pressure respirator (model SN-480-3, Shimano, Tokyo, Japan). The weight of experimental dogs was 13.0 ± 0.5 kg (mean ± s.e.m.) and that of larger support dogs was 24.3 ± 2.2 kg. Supplemental oxygen and sodium bicarbonate were given if necessary to maintain arterial 

\[ P_{O_2}, P_{CO_2}, \text{and pH} \]

within their physiological ranges (70–100, 30–40 torr, and 7.35–7.45, respectively). Anesthesia for the support dog was maintained constant with continuous intravenous infusion of sodium pentobarbital.

After the heart was removed from the experimental dog, the cusps of the aortic valve were sewn together and a patch was additionally sutured below the aortic valve through the mitral valve orifice (Fig. 1). A thin latex balloon (condom, 0.03 mm thick) connected to a rigid plastic cannula was inserted into the right ventricular cavity through the mitral orifice. A plastic ring which was linked to the cannula was fixed to the tricuspid orifice. One of the pacing wires was sewn to the upper portion of the interventricular septum through the tricuspid orifice and another to the atrium. The cusps of the pulmonary valve were sutured. Another thin latex balloon attached to a rigid cannula was inserted into the left ventricular cavity through the mitral orifice. To minimize the effect of latex balloon per se on the distensibility, the unstressed volume of the balloons was determined before the insertion. The tips of 6F micromanometer catheters (Millar Instruments, Houston, Texas) were fixed inside the balloons of the right and left ventricles through the cannulae. The balloons were filled with saline, and their volumes were controlled manually using a syringe connected to the outlet cannulae. Drainages were set in the apexes of the right and left ventricles to decompress these chambers from any Thebussian drainage. The ascending aorta of the isolated heart was cannulated and connected to the perfusion line. The perfusion line was connected to the femoral artery of the heparinized support dog. The isolated ventricle was suspended by a clamp at the top of the cannula.

In four of eight experimental hearts, wall thickness of the right and left ventricular free wall was sonomicroscopically measured. A pair of crystals (5 MHz) for right ventricular free wall was implanted at the midpoint between the tricuspid valve and the pulmonary valve. Crystals for left ventricular free wall thickness were implanted at the left ventricular lateral wall. We introduced and implanted endocardial crystals (2.5 and 1.3 mm in diameter and thickness, respectively) through the tricuspid or mitral valve orifices. The endocardial crystal for RV or LV free wall was inserted under direct observation just beneath the endocardium of the trabecular carnea through a slit in the endocardial surface and the slit was thinly sutured with fine strings. The other crystal, attached to a cloth patch, was sewn to the epicardium of RV or LV free wall with shallow sutures after location of the position of least distance between the crystals while monitoring the signals with an oscilloscope.

Coronary perfusion pressure was measured at the perfusion circuit near the ascending aorta of the isolated heart through a fluid-filled cannula (P23Db strain gauge manometer; Statham, Oxford, California). Coronary flow was measured by a cannulation type electromagnetic flow probe (ME-27, Nihon Koden). Coronary perfusion pressure and/or flow was controlled by a roller pump (model 5745, PEMCO Inc., Cleveland, Ohio). The return flow to the support dog was also adjusted by another roller pump and was set at the same rate as the perfusion flow from the support dog. The circuit included a Windkessel register to attenuate the pulsatile wave. The register and a container of the blood which perfused the isolated heart were warmed by a thermostat bath at 37°C.

Five minutes after the perfusion line was opened, the isolated heart was electrically defibrillated on the atria. The heart was paced at a constant rate of 120–140 beats/min with bipolar electrodes on the upper septum and the atrium.

2.2. Experimental protocol

It has been reported that right coronary autoregulation is less pronounced than left coronary autoregulation [19–21].
Therefore, we eliminated the autoregulatory control of the right and left coronary arteries by infusing adenosine (0.6 mg/min) into the ascending aorta of the experimental heart throughout the experiment. The resultant adenosine concentration corrected by coronary blood flow after the infusion was 14 ± 2 μM. In preliminary experiments, we confirmed that the dose of adenosine was sufficient to eliminate the apparent level of coronary autoregulation. After confirming that the right and left ventricular pressures were stable, the data were collected according to the following protocols.

At 73 ± 1 mmHg of the mean coronary perfusion pressure (coronary flow 166 ± 16 ml/min), we increased the left ventricular volume stepwise by 1 or 2 ml from 10.5 ± 1.8 ml to 21.5 ± 2.8 ml. As a result, left ventricular systolic pressure increased from 48.9 ± 4.6 mmHg to 101.5 ± 6.2 mmHg. During the procedure, the right ventricle was fixed at a relatively small volume (11.4 ± 2.1 ml). After measurements of the left ventricular pressure–volume relation, right ventricular volume was increased stepwise from 11.6 ± 2.2 ml (resultant systolic pressure: 19.3 ± 1.5 mmHg) to 19.1 ± 3.2 ml (42.4 ± 2.4 mmHg), while the left ventricle was fixed at a relatively small volume (10.9 ± 1.6 ml). A few minutes after the mean coronary perfusion pressure was increased to 152 ± 6 mmHg (coronary flow 377 ± 29 ml/min), these procedures were repeated and the left and right ventricular pressure–volume relations were measured. The order of the measurement of left and right ventricular pressure–volume relations was random.

Diastolic and systolic pressures of the one ventricle are influenced by the level of the ventricular pressure and/or volume of the other [18,22]. Experimental data were obtained under the condition that the other ventricle was fixed at a relatively small volume. Based on the pressure gains for ventricular interaction calculated from our previous study [18], the estimated pressure enhancements of one ventricle elicited by the pressure increase of the other small ventricle accompanied by an increase in perfusion pressure or flow were less than 0.2 mmHg in diastole and 1.0 mmHg in systole in both ventricles.

### 2.3. Data analysis

End-diastolic was defined as the time when the ventricular pressure increases abruptly. To compare the changes in end-diastolic pressure during an increase in perfusion pressure between right and left ventricles, the volume of both ventricles was selected so that the end-diastolic pressure in the control state was similar between the right and the left ventricle. In each experiment, the difference between the right and left ventricular end-diastolic pressures was within 1 mmHg at small ventricular volume and within 2 mmHg at large ventricular volume. Middle volume was a median between the large and the small volume.

Right and left ventricular end-systolic pressures were defined as the peak systolic pressures. A least-squares linear regression was applied to generate the slope (E\(_{es}\)) and the volume axis intercept (V\(_{es}\)) of the right and left ventricular end-systolic pressure–volume relations. The mean values of coefficients of the regression analysis were 0.998 (0.998–0.999) in the right ventricle and 0.999 (0.998–0.999) in the left ventricle. Pressure–volume area (PVA) was defined as an area surrounded by the line of the end-systolic pressure–volume relation and the curve of diastolic pressure–volume relation in the right or the left ventricle. The diastolic pressure–volume relations of the right and left ventricles were fit to an exponential curve, \( P = A \cdot e^{kV} \); where P and V are pressure and volume, respectively and A and k are constant.

### 2.4. Statistical analysis

All results are expressed as mean ± s.e.m. Student’s \( t \) test for paired observations was used to assess the significance of the differences in continuous data. Comparison of PVA before and after increasing perfusion pressure was assessed by Wilcoxon signed-rank test. The changes in end-diastolic pressure among three different volumes were compared by repeated-measures analysis of variance. When this indicated a significance difference among the three conditions, Fisher protected least significant difference for multiple comparisons was used to determine the significance of difference between the conditions. A value of \( P < 0.05 \) was considered a statistically significant difference.

### 3. Results

The original tracings of pressures and flow signal from a representative experiment are shown in Fig. 2. The right and left ventricular volume was fixed constant. Following the increase in the mean coronary perfusion pressure from 72 mmHg (blood flow 180 ml/min) to 155 mmHg (400 ml/min), the end-diastolic pressure increased from 8.2 to 10.2 mmHg in the right ventricle and from 9.4 to 13.4 mmHg in the left ventricle. On the other hand, the systolic pressure increased from 42 to 46 mmHg in the right ventricle and from 106 to 139 mmHg in the left ventricle. Although the increase in coronary perfusion pressure was similar in the right and left coronary arteries, the absolute and percent changes of the end-diastolic or the end-systolic pressure were less in the right ventricle than the left ventricle.

### 3.1. Diastolic property

Right and left ventricular diastolic pressure–volume relations of a representative heart are illustrated in Fig. 3. After an increase in perfusion pressure, the end diastolic pressure increased at each level of the volume in both
Perfusion pressure coronary flow AoP of support dog (mmHg)

Fig. 2. Tracing from a representative experiment before and after the abrupt increase in perfusion pressure and/or coronary flow on the right and left ventricular pressure (RVP and LVP) at the same RV and LV volume. Aortic pressure (AoP) of a support dog remains constant during the procedure. Following the increase in mean coronary perfusion pressure and flow, the resultant elevation in end-diastolic or end-systolic pressure was less in the RV than the LV (see detail in the text).

In eight experiments, right ventricular end-diastolic pressure increased from 1.2 to 1.6 mmHg at 10 ml of the right ventricle and from 11.0 to 15.2 mmHg at 20 ml of the right ventricle. Left ventricular end-diastolic pressure increased from 2.0 to 3.2 mmHg at 10 ml of the left ventricle and from 9.8 to 24.4 mmHg at 20 ml of the left ventricle. The right and left ventricular end-diastolic pressure-volume relations shift upward and leftward, and the extent of the shift seems less in the right than the left ventricle.

In eight experiments, right ventricular end-diastolic pressure after increasing the coronary perfusion pressure significantly rose at each level of the right ventricular volume (3.9 ± 0.5 to 4.5 ± 0.6 mmHg at the small (P < 0.05), 7.1 ± 0.8 to 8.6 ± 1.0 mmHg at the middle (P < 0.01), and 13.9 ± 0.8 to 16.8 ± 1.2 mmHg at the large right ventricular volume (P < 0.01)) (Fig. 4). Left ventricular end-diastolic pressure concomitantly increased from 4.0 ± 0.5, 8.2 ± 0.7, and 14.5 ± 0.9 to 5.8 ± 0.5, 12.4 ± 1.2 and 23.4 ± 2.3 mmHg at the small, middle, and large left ventricular volume, respectively (P < 0.01). Changes in end-diastolic pressure from control to an increased level of the coronary perfusion pressure were smaller in the right than in the left ventricle (1.5 ± 0.3 vs 4.3 ± 0.9 mmHg at middle volume and 2.8 ± 0.8 vs 8.9 ± 2.0 mmHg at large volume; P < 0.01) (Fig. 5). The larger the ventricular volume set, the larger the effect of increasing coronary perfusion pressure on the end-diastolic pressure in either ventricle (Fig. 5).

3.2. Systolic performance

The effect of increasing perfusion pressure on the end-systolic pressure-volume relation of a representative experiment is depicted in Fig. 6. With an augmentation of coronary perfusion pressure, the slope of the end-systolic pressure-volume relation, Esv, increased in the right as well as the left ventricle. The perfusion pressure-induced increase in Esv was less pronounced in the right than in the left ventricle. The volume axis intercept, V0, was relatively constant during changes in coronary perfusion pressure in both ventricles. PVA increased by 21% in the right ventricle and by 46% in the left ventricle.

In eight experiments, an elevation of coronary perfusion pressure augmented the right ventricular Fsv by 11 ± 6% from 3.0 ± 0.6 mmHg/ml to 3.3 ± 0.7 mmHg/ml (P <
Ventricular Volume

Fig. 5. Changes in end-diastolic pressure (EDP) induced by an increase in coronary perfusion pressure. The increase in right ventricular (RV) EDP was smaller than that in left ventricular (LV) EDP at middle (M) and large (L) ventricular volume. A, P < 0.01 vs the corresponding left ventricle; B, P < 0.01 vs small (S) ventricular volume; C, P < 0.01 vs middle (M) ventricular volume.

Fig. 6. Right ventricular (RV; left panel) and left ventricular (LV; right panel) pressure–volume relations of a representative experiment in a control run (open circles) and in a hyperperfusion run (closed circles). With an increase in perfusion pressure, the slope of the RV end-systolic pressure–volume relation, $E_{es}$, was increased by 16% from 3.1 to 3.6 mmHg/ml. LV-$E_{es}$ was increased by 39% from 5.1 to 7.1 mmHg/ml. The volume axis intercept, $V_0$, remained almost constant at 4.7 and 4.5 ml in the RV, and at 3.9 and 3.4 ml in the LV. An increase in perfusion pressure increased the RV pressure–volume area (shaded area), PVA, by 21% from 146 to 176 mmHg/ml. LV-PVA was increased by 46% from 562 to 819 mmHg/ml. RVV, RV volume; LVV, LV volume.

Fig. 7. Slope ($E_{es}$) of the right and left ventricular (RV and LV) end-systolic pressure–volume relations before (C) and after coronary hyperperfusion (HP). Percent change in RV-$E_{es}$ tended to be smaller than that in LV-$E_{es}$ ($P > 0.12$). * $P < 0.05$ vs control, ** $P < 0.01$ vs control.

Fig. 8. Pressure–volume area (PVA) of right and left ventricle (RV and LV) before (C) and after coronary hyperperfusion (HP). During HP, RV- and LV-PVA significantly increased. Percent change in RV-PVA was smaller than that in LV-PVA. * $P < 0.05$ vs control, ** $P < 0.05$ vs left ventricle.

Fig. 9. Right ventricular (RV; left panel) and left ventricular (LV; right panel) pressure–volume relations of a representative experiment in a control run (open circles) and in a hyperperfusion run (closed circles). With an increase in perfusion pressure, the slope of the RV end-systolic pressure–volume relation, $E_{es}$, was increased by 16% from 3.1 to 3.6 mmHg/ml. LV-$E_{es}$ was increased by 39% from 5.1 to 7.1 mmHg/ml. The volume axis intercept, $V_0$, remained almost constant at 4.7 and 4.5 ml in the RV, and at 3.9 and 3.4 ml in the LV. An increase in perfusion pressure increased the RV pressure–volume area (shaded area), PVA, by 21% from 146 to 176 mmHg/ml. LV-PVA was increased by 46% from 562 to 819 mmHg/ml. RVV, RV volume; LVV, LV volume.

4. Discussion

The results of the present study show that with increasing coronary perfusion pressure and/or flow: (1) Diastolic distensibility decreased in the right ventricle as well as the left ventricle; however, the alteration of the diastolic distensibility was less pronounced in the right ventricle than the left ventricle. (2) The ventricular contractility index, $E_{es}$, significantly increased in both ventricles. (3) The integral of developed pressure along the ventricular volume or PVA was less augmented in the right ventricle than the left ventricle. Thus, the coronary hyperperfusion elicits both "erectile" effect and enhanced contractile performance in the right ventricle as well as the left ventricle. However, the manifestations of these phenomena are less prominent in the right ventricle.
4.1. Alterations of diastolic pressure-volume relation with increasing coronary perfusion

Salisbury et al. first demonstrated that acute changes in coronary perfusion pressure caused significant changes in ventricular diastolic pressure; this phenomenon was attributed to an "erectile" effect of the coronary vasculature [2]. In the present study, elevation of coronary perfusion pressure elicited substantial decreases in right as well as left ventricular distensibility. Such effects became prominent when the ventricles operated on the steeper portion of the pressure-volume curve. We demonstrated that an increase in coronary perfusion pressure decreased the right ventricular distensibility as observed in the left ventricle, and that such alteration of the diastolic property was less potent in the right than the left ventricle. A few investigators [10,21] reported, in situ heart preparations, that an increase in perfusion pressure did not significantly alter the right ventricular end-diastolic pressure. The discrepancy between the previous investigations and the present study may originate from the differences in the experimental conditions. Since right ventricular volume was not controlled in the previous studies, the change in right ventricular distensibility may have decreased the right ventricular volume during the hyperperfusion in their in situ hearts and, consequently, an elevation of right ventricular diastolic pressure may not be found. Alternatively, changes in right ventricular end-diastolic pressure may have been attenuated due to the operation at the lower flat portion of the pressure-volume curve in their in situ hearts.

At present, it appears more likely that changes in perfusion pressure and/or flow do not primarily affect properties of ventricular myocytes per se, such as elastic or viscous properties, but rather changes in the ventricular volume to the wall thickness ratio. Increasing perfusion pressure or flow affects the coronary vascular volume and the ventricular wall thickness [23–25]. An increase in myocardial wall thickness may contribute to increases in ventricular diastolic pressure. In the present study, the increase in wall thickness was observed in the right as well as left ventricular free wall. An increase in myocardial wall thickness during increased level of coronary perfusion has been shown to be accompanied by an elongation in myocardial sarcomere length in the mid and outer layer of the ventricular wall without changes in the chamber volume [26,27]. Accordingly, the apparent increases in the right and left ventricular diastolic pressure at the constant level of intracavity volume may be caused by increases in wall tension of the outer shell of the ventricular wall.

An inequality of erectile responses between the right and left ventricles during the same elevation of the coronary perfusion pressure was an unique finding in the present study. A few mechanisms inherent to the architecture of these ventricles may play a role in the different responses. Firstly, the increase in blood volume in the capacitance vessels may differ between the right and left coronary arteries. Right coronary autoregulation is less pronounced than left coronary autoregulation [19–21] and therefore, the autoregulatory control of the right and left coronary arteries was eliminated by infusing adenosine into the heart throughout the experiment. We sonomicrometrically measured wall thickness of the ventricles which is related to the blood volume in coronary capacitance vessels [4,23–26]. During an increase in perfusion pressure, an increase in wall thickness of the right ventricular free wall was similar to that of the left ventricular free wall. Secondly, the geometrical disparities between the right and the left ventricles can explain why the effect of an increased perfusion pressure on diastolic pressure-volume relation is less pronounced in the right ventricle. The right ventricular free wall is thinner than the left ventricular free wall and therefore, even if both ventricles decrease in blood volume in each wall, the actual increase in fiber length in the outer layer of the wall should be smaller in the right ventricle. Furthermore, the radius of curvature in the right ventricle is larger than that in the left ventricle. If the radius of curvature of a ventricle is extremely large, an increase in the wall thickness of the ventricle should not cause an increase in the myocardial fiber length. Thus, larger radius of curvature in the right ventricle may be related to a less pronounced effect of increasing perfusion pressure in the right ventricular diastolic pressure-volume relation. Thirdly, the right ventricular free wall may not play a crucial role for the right ventricular diastolic pressure during altered perfusion pressure, since the right ventricular free wall encloses only a portion of the right ventricular volume.

4.2. Alteration of systolic pressure-volume relation and pressure volume area following increases in coronary perfusion pressure

Since Gregg [8] documented the intimate relation between the elevation of coronary perfusion pressure and the increase of $\dot{V}_{O_2}$, increased levels of cardiac contractility or metabolic state have been repeatedly examined during an increase in coronary perfusion pressure or flow [5–10]. However, the previous investigations have been focused on the left ventricle and only a few investigators examined the phenomenon in the right ventricle [10]. In the present study, an increase in coronary perfusion pressure significantly increased the right ventricular $E_{ps}$, as investigated in the left ventricle. Namely, contractile performance in the right ventricle was also enhanced by an increase in coronary perfusion pressure.

The use of end-systolic pressure-volume relation as contractile performance may be partly limited when the diastolic pressure at a given ventricular volume is greatly increased. The upward shift of the diastolic pressure-volume relation may alter the end-systolic pressure-volume relation independently of the ventricular contractility [28]. Pressure-volume area, PVA, has been demonstrated to
represent the total mechanical energy produced by the ventricle and to be closely related to the ventricular oxygen consumption [29,30]. As another usefulness of PVA, PVA includes changes in diastolic property and therefore, PVA may reflect more precisely the level of ventricular pump performance in the condition that the diastolic pressure-volume relation greatly alters [28]. Following an increase in coronary perfusion pressure, an increase in PVA in the right ventricle was about half of that of the left ventricle. Thus, enhancement of contractile performance may be less pronounced in the right than the left ventricle during an increase in perfusion pressure or flow.

The oxygen consumption of the right or left ventricle was not measured in the present study, because techniques to measure coronary blood flow and oxygen content of venous blood supplied to the right ventricle were not feasible. Suga et al. reported that an increase in PVA was linearly related to an increased level of oxygen consumption in the right ventricle as shown in the left ventricle [31]. Accordingly, an observed increase in PVA during an increase in perfusion pressure and/or flow may be accompanied by an increase in oxygen consumption in the right and left ventricles.

The mechanism involved in the differences of the enhanced contractile function during hyperperfusion between the ventricles is not clear from the present investigation. The increased myocardial fiber length during diastole results in an increase in force generation via Starling’s law. The alteration of the fiber length derived from an increased wall thickness contributes partly to an increase in force generation. After increasing perfusion pressure and/or flow, lesser magnitude of the enhanced contractile function in the right ventricle compared to the left ventricle was an unique finding in the present study. Although the change in wall thickness was similar between the ventricles, the actual increase in fiber length may be smaller in the right than the left ventricle because of the thinner wall and larger radius of curvature in the right ventricle. Thus, the difference in the increase in the myocardial fiber length of each wall may partly explain the inequality of the enhanced contractile performance between the right and left ventricle.

Recently, the time-varying elastance concept for the ventricle was also applied to the lumen of the coronary vasculature [32]. If this is the case, the total ventricular elastance implies the sum of the ventricular myocardial elastance and the coronary elastance. It may be possible that the increase in elastance of the right coronary vasculature is less than that of the left coronary vasculature. In other words, a given change in coronary perfusion pressure may affect coronary flow differently in the right ventricle and the left ventricle despite similar vascular density and an absent coronary autoregulation in the present study.

It has been shown that the intracellular calcium transient was increased during systole when coronary perfusion and flow were elevated in isolated ferret [33] and rat [34] hearts. Intracellular calcium plays an important regulatory role in a series of physiological changes, especially changes in mechanical function, induced by altered coronary perfusion. However, the precise mechanisms for an increase in intracellular calcium associated with altered coronary perfusion are not known. Myocardial stretch-activated channels may be one possible explanation for the augmentation of the amplitudes in intracellular calcium [35]. Alternatively, the increase in coronary perfusion pressure and/or flow may release substances from the vascular and endocardial endothelium [36-39] and then, the substances may enhance the ventricular performance with changes in intracellular calcium transient. However, a role of the endothelium [13,37,39] in Gregg’s phenomenon and the difference of the endothelial effect between the right and left ventricle await further investigations.

4.3. Limitation

During the surgical procedure of this study, the myocardium of the experimental heart might be stunned. Although the developed pressure of the two ventricles was slightly smaller after perfusing the heart with the blood of a supporting dog, the developed pressures were gradually increased and were stable for a long time. Stunning should occur similarly in both ventricles. Thus, our major finding is considered not to be affected by stunning of the myocardium after the surgical procedure.

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