IN SITU PAPILLARY MUSCLE PREPARATION AND SOME BASIC CONTRACTILE PROPERTIES

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Abstract A method of preparing an in situ papillary muscle in an excised, cross-circulated heart was developed and its basic contractile properties were studied. The preparation was instituted without any interruption of coronary perfusion with arterial blood. The coronary perfusion pressure was 103±8 (SD, 10 muscles) mmHg. The temperature of the perfusing blood was kept at 37°C. The preparation beat at a regular rate of 97±16 beats/min. The maximal developed force of contraction, which was measured with a specially devised isometric force transducer, was 60±13 g. When this was divided by the cross sectional area of the papillary muscle, it was 630±66 g/cm². The developed force and heart rate were stable for 4 to 6 hr as long as anesthesia of the support dog was well maintained. When the coronary perfusion pressure was reduced to 50 mmHg, the developed force decreased by 33±24%. On occlusion of both common carotid arteries of the support dog, the developed force increased by 38±17% while the coronary perfusion pressure was kept unchanged.

The conventional excised and artificially perfused papillary muscle preparation has the disadvantage that it has a damaged region near the clamped end. The region seems to have a relatively large compliance, which limits the usefulness of the excised preparation for physiological studies of myocardial mechanics (KRUEGER et al., 1975). An in situ papillary muscle preparation seems to be free from such a disadvantage and to promise better understanding of myocardial contraction.

We developed a method of instituting an in situ papillary muscle preparation in the excised, metabolically supported heart. We devised an isometric force transducer and measured both resting and developed force of the in situ papillary muscle.
METHODS

Excised, cross-circulated heart. First, the excised heart preparation was instituted without any interruption of coronary perfusion with arterial blood. The method was the same as previously used (SUGA and SAGAWA, 1974). Briefly, in each experiment two dogs were anesthetized iv. with a mixture of alpha-chloralose (60 mg/kg) and urethane (600 mg/kg). Both femoral arteries and veins of one dog, used as a support dog, were cannulated. Under an artificial respiration, the other dog was thoracotomized midsternally. The left subclavian artery was cannulated and connected to the arterial tubing from the support dog. The right ventricle was cannulated via the right atrium and drained into the funnel which had been connected to the venous tubing from the support dog.

Snares were placed around the descending aorta, the brachiocephalic artery, the superior and inferior caval veins and the azygos vein. All the snares were tied in the order of the azygos, then the aorta and the inferior simultaneously, and finally the brachiocephalic and the superior so that the aortic pressure was kept about normal. The heart lung preparation was now completed.

All the pulmonary hili were ligated and the respirator was stopped. The

Fig. 1. Schematic drawing of the in situ right-heart papillary muscle preparation in the canine excised, cross-circulated heart. A: right atrium, B: metal base ring of the force transducer (TR), COR: arterial tubing from the support dog to the aortic arch of the excised heart, PM: papillary muscle, S: tubing to drip arterial blood on the papillary muscle, SG: strain gauge, V: tricuspid valve, and W: free wall.
cross circulation started at this moment. The supported heart was excised from
the thorax and hung above the funnel.

*In situ papillary muscle.* The right ventricular free wall was opened to expose
anterior papillary muscles. Major coronary bleeding was stopped by ligation.

A newly devised isometric force transducer (compliance: 60 μ/10 g) was ap-
plied to one papillary muscle, as shown in Fig. 1. The muscular end of the chorda
tendinea was tied with a 3-0 silk thread and the chorda was cut. The muscle was
put through the metal base ring of the transducer. The base was pressed down
on the septum to pin it deeply with the three pins of the base. Since the papillary
muscle was supplied with a branch of the septal artery from the valvular side
(BLAIR, 1961; LANGER and BRADY, 1963), a care was taken to avoid pinning of
the region. The ligature of the chorda was tied to the hook of the transducer.
The free wall and the valves were sutured to the base of the transducer at 3 or 4
sites. By turning the screw of the transducer, the isometric length and therefore
the resting force of the papillary muscle were varied.

A part of the arterial tubing was coiled and dipped into a thermostat bath to
keep the temperature of the perfusing blood at 37°C. A branch tube from the
arterial tubing was used to drip arterial blood on the papillary muscle to avoid
the drying of the muscle's surface.

The effective pressure of the coronary perfusion was equal to mean arterial
pressure of the support dog minus the height difference between the dog and the
heart (10 to 20 cm). This height difference was necessary for the venous return
from the funnel to the dog. A screw clamp on the arterial tubing was used to
decrease the pressure.

At the end of each experiment, the muscle was released from the hook and
the base of the transducer, and kept unstretched. The length of the muscle in
this condition was the slack length. The major and minor diameters, D and d,
of the muscle's stalk were measured with calipers. The cross sectional area
of the muscle was given by \( \pi \cdot D \cdot d / 4 \), since the cross section was ellipsoid.

**RESULTS**

Ten papillary preparations of 8 to 12-kg mongrel dogs of either sex were
studied. Coronary perfusion pressure was 103±8 (SD) mmHg. Preparations
beat at a regular rate of 97±16 beats/min, although extrasystoles were observed
occasionally. Changes in the isometric length occasionally and transiently pro-
duced extrasystoles.

By turning the screw of the transducer, the isometric length was varied from
the slack length (where both resting and developed force were zero) to a length
slightly beyond the so-called \( L_{\text{max}} \) (where the developed force became maximal).
Figure 2 shows an example of the run. The slack length was 14.5±2.3 mm and
\( L_{\text{max}} \) was 4.8±1.8 mm longer than the slack length. The maximal developed
force (total minus resting) was 60±13 g. Since the cross sectional area of the
muscles was $0.092 \pm 0.026 \text{ cm}^2$, the maximal developed force per unit cross sectional area, or stress, was $630 \pm 66 \text{ g/cm}^2$. The resting force at $L_{\text{max}}$ was $53 \pm 23 \text{ g}$.

The preparations with a resting force of 8 to 12 g kept contracting for 4 to
6 hr without significant fall of the developed force and change in heart rate when the support dog's anesthesia was stable.

The developed force varied with changes in the coronary perfusion pressure, as shown in Fig. 3. When the pressure was reduced to 50 mmHg from the control, the developed force of the preparations with a resting force of 8 to 12 g decreased by $33\pm24\%$ in a steady state at 1 to 2 min after the step change.

The developed force was dependent also on humoral inotropic agents in the arterial blood. As shown in Fig. 4, the developed force at a resting force of 8 to 12 g increased $38\pm17\%$ on occlusion of both common carotid arteries of the support dog, which increased the tone of the sympathoadrenal system. The coronary perfusion pressure was maintained at the same level as the control during the occlusion. Heart rate increased by $25\pm19\%$ simultaneously.

Postextrasystolic beats following spontaneous extrasystoles produced the developed force greater than the regular beats. The largest value of such greater developed force in the individual preparations amounted to $93\pm23$ g, or $1030\pm120$ g/cm², being read from the tracings regardless of the resting force values.

**DISCUSSION**

The in situ papillary muscle preparation enabled us to measure the contractile force in a stable physiological condition. The maximal developed force of the preparation was comparable with that of the conventional preparation of the excised, well oxygenated papillary muscle (BRUTSAERT et al., 1971), although the beat of the latter was at lower temperature and stimulus frequency.

KAVALER et al. (1971) have developed a different type of in situ papillary muscle preparation. They isolated the right heart with a total cardiopulmonary bypass, and exposed the anterior papillary muscles. The maximal developed force they reported is comparable with ours. Differences of our preparation from theirs are that 1) our heart was excised whereas theirs was in situ, 2) the excision denervated the heart completely and the denervation eliminated neural changes in inotropic background and stabilized the contractility, and 3) the cross circulation enabled the control of the coronary perfusion pressure. Changes in humoral inotropic background affect both preparations.

Judging from the stability and contractility of our in situ papillary muscle preparation, we consider that the present preparation is potentially useful for physiological studies of papillary muscle mechanics.

**REFERENCES**


