In Vivo Papillary Muscle Responses to Cardiac Nerve Stimulation[1] (34601)

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The role of the papillary muscles has been a subject of controversy for many decades, although it is generally assumed that they function to control the positioning of the atrioventricular valves. However, recent surgical experience has been interpreted to indicate that the papillary muscles do not significantly influence function of the left ventricle (1, 2). Alterations of cardiodynamics brought about by ischemic infarction of the papillary muscles is sometimes considered to be due only to valvular incompetence (3). Although recordings have been obtained from the chordeae tendineae (4, 5), until recently (6) no direct records of papillary muscle contractile function *in situ* have been reported. The importance of this structure in myocardial dynamics is regularly assumed, but so far it has been primarily a subject based upon conjecture rather than fact (7).

The papillary muscles received a generous nervous supply and both positive and negative inotropic responses to sympathetic and parasympathetic stimulation, respectively, have been reported from this laboratory (6). The papillary muscles were also shown to respond differently to direct influences of norepinephrine, isoproterenol, and methoxamine, as well as the passive influences of elevated afterload induced by cross clamping of the aorta (6). However, the differential innervation of the anterior and posterior muscles has not been reported heretofore, and this communication describes their responses to electrical excitation of the small cardiac nerves.

Material and Methods. Thirty mongrel dogs of either sex, weighing from 15–26 kg were anesthetized with intramuscular phencyclidine hydrochloride (2 mg/kg) and intravenous alpha chloralose (80 mg/kg). A bilateral thoracotomy was performed and the stellate ganglia and cervical vagosympathetic trunks were isolated. The animal was placed upon total cardiopulmonary bypass with a single venous drain in the right atrium and a single return in a femoral artery. The heart was fibrillated and while on total bypass the left atrium was opened, the mitral valve retracted, and the left ventricle decompressed with continuous suction. A Walton-Brodie strain gauge arch was sutured along the longitudinal axis of the anterior and posterior papillary muscles. Identical gauges were also applied to epicardial muscle segments immediately overlying the papillary muscles. The gauges were calibrated with known weights and the response found to be linear over the length changes employed. Following closure of the atriotomy, the hert was defibrillated and the animal removed from bypass. Autopsy was performed with the gauges still attached, in order to verify location, and one suture cut while the recorder was in operation, in order to ascertain the existence of diastolic tension on the gauge. Recordings were made on a Model 7 Grass polygraph with pressure measurements from Statham P23db pressure transducers. Nerve stimulations were performed with a Grass S-5 stimulator with rectangular pulses of 4–5 V 10 cps, and 5 msec duration. Stimulation pulses were monitored continuously on an oscilloscope.

Results. Fig. 1 reveals the simultaneous changes in contractile force on several different myocardial segments, including both the anterior (APM) and posterior (PPM) papil-

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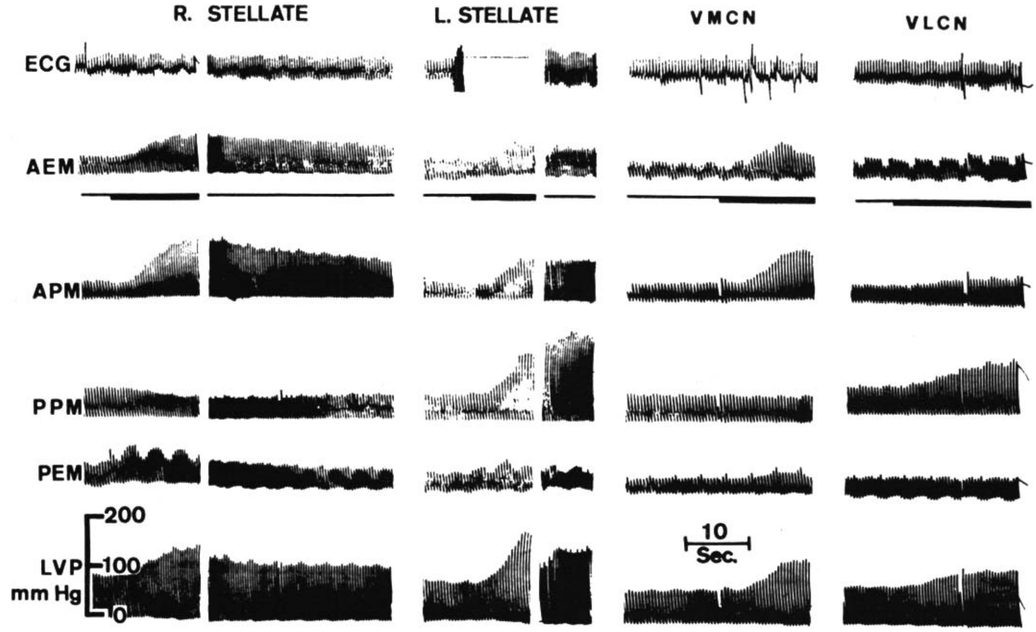

FIG. 1. Responses of both epicardial and endocardial muscle segments to stimulation of the right and left sympathetic cardiac nerves. From above downward, recordings were made from lead II of the electrocardiogram (ECG), contractile force from the anterior surface of the left ventricular epicardium (AEM), anterior papillary muscle (APM), posterior papillary muscle (PPM), both of the latter in the left ventricle, posterior epicardial surface of the left ventricle (PEM), and left ventricular pressure (LVP). The signal shows the initial portion of the stimulation period with recovery following. VLCN = ventrolateral cervical cardiac nerve and VMCN refers to the ventromedial cervical cardiac nerve.

lary muscles of the left ventricle during electrical excitation of specific portions of the sympathetic cardiac innervation. Attention is called specifically to the differential augmentation of contractile force in response to such stimulation. In a majority of animals studied, excitation of the stellate ganglia elicited a generalized increase in contractile force, as well as in rate of change in force, on all epicardial segments (PEM, AEM) of the heart. Heart rate and intraventricular pressure changes also generally accompanied such stimulation. During stimulation of the right stellate ganglion (left panel) augmented contractile force was clearly apparent on all myocardial segments except the PPM. During excitation of the left stellate ganglion, this muscle responded with the greatest percent change in contractile force. Although the APM showed an augmented response, it was considereably less marked than that induced by the right stellate. The ventrolateral cervical cardiac nerve (VLCN) and the ventromedial cervical cardiac nerve (VMCN) both descend from the left caudal cervical ganglion to provide important sympathetic nerves to the heart. Electrical excitation of the VMCN produced marked augmentation in force of contraction of APM with no visible influence upon PPM, whereas stimulation of the VLCN induced distinct augmentation in the contraction of PPM with relatively little influence upon APM. Thus, inotropic fibers present in the left sympathetics appear to supply both papillary muscles, but follow anatomically different routes from the stellate ganglion to the endocardial structures. In several instances, decreased amplitudes of force tracings invite interpretation in terms of negative inotropic actions of the stimulated nerves (see PPM during right stellate stimulation). Caution against such interpretation must be emphasized, however, since the possibility of mechanical influence

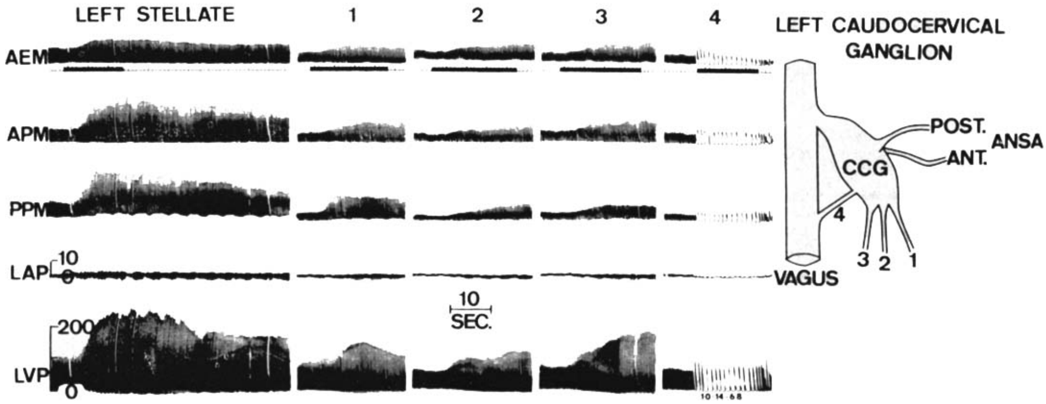

FIG. 2. The responses of both papillary muscles to stimulation of the left stellate ganglion and distal branches of that ganglion. AEM = Anterior epicardial contraction, APM = Anterior papillary muscle contraction, PPM = Posterior papillary muscle contraction. LAP = Left atrial pressure, 0 to 10 mm Hg. LVP = Left ventricular pressure, 0 to 100 mm Hg.

transmitted from the activity of adjacent myocardial segments may account, at least in part, for such changes.

Figures 2 and 3 further illustrate the highly localized control exercised by the autonomic nervous system over the individual papillary muscles of the left ventricle. In the left panel of Fig. 2, left stellate ganglion stimulation produced a marked rise in left ventricular pressure (LVP) from 100 to 250 mm Hg with no evidence of mitral incompetence. Left ventricular anterior epicardial contractile force was augmented, but considerably less than that simultaneously induced in the papillary muscles. When the distal branches of the caudal cervical ganglion were stimulated, variations in localized augmentation became evident. Stimulation of the most lateral branch (No. 1) of the sympathetic outflow from the caudal cervical ganglion (CCG) elicited augmentation in all test segments with predominance in the PPM. It is evident that the magnitude of change in contractile force and pressure was markedly re-

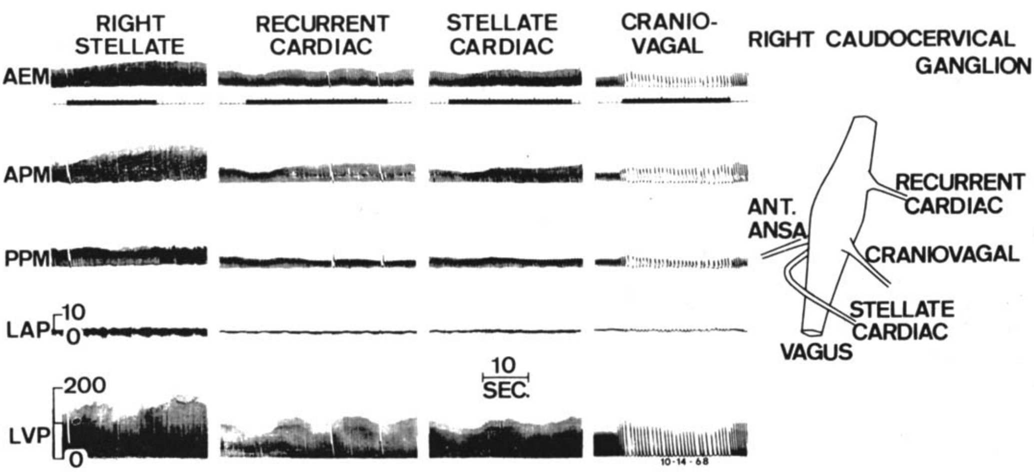

FIG. 3. The response of both papillary muscles to stimulation of the right stellate ganglion and its distal branches of that ganglion. AEM = Anterior epicardial contraction, APM = Anterior papillary muscle contraction. PPM = Posterior papillary muscle contraction. LAP = Left atrial pressure, 0 to 10 mm Hg. LVP = Left ventricular pressure, 0 to 100 mm Hg.

TABLE I. Papillary Muscle Response to Cardiac Nerve Stimulation.

Neural stimulation	No. animals	LVSP (mm Hg)	HR (beats/min)	Percent of control contractile force: Anterior epicardium	Anterior pap. muscle	Posterior pap. muscle	p value
Control	20	90 ± 4	122 ± 3	100	100	100	—
Right stellate	20	149 ± 11	175 ± 14	198 ± 4	338 ± 61	247 ± 29	0.001
Recurrent cardiac n.	12	116 ± 8	127 ± 7	142 ± 11	173 ± 16	135 ± 29	0.02
Stellate cardiac n.	12	95 ± 2	165 ± 11	107 ± 11	113 ± 13	103 ± 4	0.02
Left stellate	20	156 ± 16	187 ± 15	198 ± 11	477 ± 55	467 ± 71	1.00
Ventromedial cardiac n.	14	117 ± 7	135 ± 9	164 ± 18	209 ± 14	135 ± 14	0.001
Ventrolateral cardiac n.	15	129 ± 10	142 ± 6	143 ± 24	165 ± 12	283 ± 31	0.001
Caudal vagal cardiac n.	13	62 ± 4	63 ± 6	81 ± 5	75 ± 5	71 ± 9	1.00

duced. When the second branch was stimulated, augmentation was uniformly induced in all of the test segments (No. 2) with a distinct alteration in the nature of the PPM response. With stimulation of the third branch the anterior papillary muscle and overlying epicardium were primarily activated. Note that with a considerable rise in LVP the posterior papillary muscle force was minimally augmented. When the fourth branch was stimulated, bradycardia typical of parasympathetic excitation occurred.

When the right sympathetic nerves in the same animal were stimulated (Fig. 3) distinctly different response patterns were induced. The right stellate ganglion, although causing lesser elevation in LVP, accentuated contraction of the APM with lesser augmentation of the anterior epicardial segment. The PPM showed no alteration in contractile force. Electrical excitation of the recurrent cardiac nerve augmented anterior papillary and epicardial muscle contractile force without influence on posterior papillary force. The stellate cardiac nerve caused increased heart rate with little augmentation on any of the test segments. The response to craniovagal excitation was primarily expressed as a marked bradycardia.

Table I summarizes the differential myocardial segment responses to sympathetic excitation, including both right and left stellate ganglia as well as specific small branches as designated by Mizeres (11). Responses are expressed in absolute terms for peak systolic left ventricular pressure (LVSP) and heart rate (HR) and percent contractile force for a myocardial segment on the anterior epicardium, as well as the APM and PPM of the left ventricle. The p value comparison between the APM and PPM responses is given in the right hand column. Responses to individual small nerve stimulation were of lesser magnitude than those to their corresponding stellate stimulation, due undoubtedly to a smaller number of fibers innervating the papillary muscles. The left sympathetic nerves have a greater influence on the left ventricular papillary muscles than do the right. Of the smaller branches on the left, the ventromedial nerve was primarily associated with augmentation in the anterior muscle while the ventrolateral nerve elicited more pronounced influence on the posterior muscle. Fig. 1 illustrates this "fine" control of the individual papillary muscles. It is of considerable interest that the recurrent cardiac branch of the right sympathetics exerts so prominent an influence on the APM of the left ventricle. It is also of interest that the stellate cardiac branch exerts nearly its entire influence on heart rate. The comparative influences are not so clearly defined when one examines only the epicardial segment of the anterior free wall of the left ventricle. The inhibitory action of all nerves containing predominantly parasympathetic fibers is demonstrated by responses to caudal vagal cardiac nerve stimulation. No differences in degree of suppression of papillary contractile force was evident.

Discussion. It has been shown recently that while electrical excitation of the stellate ganglia induces alterations in myocardial contractile force on most if not all epicardial surfaces, stimulation of small sympathetic branches at the level of the cardiac plexi resulted in responses of highly localized epicardial regions (8, 9, 10). The present studies extend these observations to include endocardial surfaces and reveal for the first time differential innervation patterns of the papillary muscles. It is also clear from these experiments that the papillary muscles participate actively in increased inotropic responses to sympathetic nerve stimulation. Although some variability exists from animal to animal, it appears that the left sympathetics influence both APM and PPM of the left ventricle, while responses to right sympathetic stimulation are confined primarily to the anterior muscle. The present studies further amplify the point that there exists specific innervation not only of highly localized segments of the epicardium but also of endocardial musculature as well.

Summary. From strain gauge arches applied to the longitudinal surface of the APM and PPM of the dog's left ventricle, patterns of mechanical contraction were recorded *in vivo* during sympathetic nerve stimulation. Profound augmentatian in force of contraction characterized these responses to excitation of the right and left stellate ganglia. Direct electrical excitation of small cardiac branches distal to the caudal cervical ganglion induced differential inotropic and chronotropic actions, depending upon the particular branch stimulated. The PPM appears to receive its primary innervation from the left cardiac sympathetic nerves, whereas the APM is supplied by both the left and right sympathetics.

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