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The Effects of Left Stellate Ganglion Stimulation on Left Ventricular Synchrony in Dogs

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THE EFFECTS OF LEFT STELLATE GANGLION STIMULATION ON LEFT VENTRICULAR SYNCHRONY IN DOGS

by

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LIFE

On August 11, 1938 Charles E. Osadjan, Jr. was born to Mr. and Mrs. Charles E. Osadjan in Chicago, Illinois. He lived in Berwyn, Illinois where he received his elementary education. In June, 1956 he graduated from St. Ignatius High School of Chicago, Illinois as the class valedictorian after having earned membership in the National Forensic League and the National Honor Society.

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In 1960 the author began work leading to the degree of Doctor of Medicine at the Stritch School of Medicine and is presently terminating those studies. The author began graduate studies in the Department of Physiology of Loyola University in September, 1961 and has combined these concomitantly with his doctoral studies. He is a member of the Student American Medical Association.

The author was married to Madeline K. Predovic, R.N. on October 20, 1962 and is the father of a son, David George.

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CHAPTER I

BACKGROUND OF THE INTRAVENTRICULAR SYNCHRONY CONCEPT

The response of the heart to stimulation by way of the stellate ganglion has been studied by many investigators over the past century and has led to the inference recently by Ulmer and Randall (24) and by Sarnoff and his co-workers (16, 19) that it includes a modification in the synchrony of myocardial contraction. Katcher and co-workers (7) demonstrated, by stereoscopic cinematography, changes in the synchrony of left ventricular segments subsequent to the injection of levarterenal. The summation of individual muscle segment shortening to produce net ventricular work was first clearly described by Wiggers (27) in 1927, and he stated that the intraventricular pressure curve "may not be regarded as an addition of ultimate contraction in phase but as a summation of rapidly succeding fractionate contractions". Since sympathetic stimulation substantially reduces the period of systole and correspondingly increases the period of diastole (13,17, 23), an altered synchronism of fiber contraction would seem to be an important influence of sympathetic innervation in producing

increased power and work.

Meticulous measurements of the sequence of ventricular excitation have been made, using epicardial electrodes, by Lewis and Rothschild in 1915 (11), by Wiggers in 1927 (27), and by Harris in 1941 (4). More precise pathways of electrical excitation have recently been traced by Scher in 1961 (21,22). The latter investigator utilized multipolar electrodes plunged into the walls and contractile tissues of the ventricles. Electrical activity began in the proximal terminations of the bundle branches, spread rapidly along the endocardial surfaces to the apical portions of the septum and papillary muscles, transmurally from endocardial to epicardial surfaces in the middle and apical free walls and finally toward the base of the walls and interventricular septum.

It is important to point out that all of the above descriptions of electrical sequential spread represent data obtained from anesthetized animals in the absence of sympathetic stimulation. From these descriptions, however, a number of presumptions have been made. First, if it were possible to record separately the successive excitation of individual segments of myocardium, it would seem reasonable to expect a parallel sequence of mechanical shortening. Secondly, it would seem reasonable to presume that the pattern of electrical excitation as demonstrated in the control state would remain essentially unchanged, as regards the basic sequence of

electrical excitation, during periods of left stellate ganglion stimulation. The facts of the matter are, however, that sequential recordings of the contraction of various myocardial segments have never been made. It has been generally presumed that the interventricular septum contracts early in systole, but this has never been documented. The photographic evidence of Puff (12) and the strain gauge data recorded from chordae tendineae by Salisbury (15) have added some data to the concept of intraventricular synchrony. Puff's high speed photographs demonstrate the asynchrony of the ventricular segments including the papillary muscle action, inflow and outflow tracts but do not include an attempt to demonstrate any alterations associated with sympathetic augmentation. Salisbury has recently attempted to measure the temporal relationship of papillary muscle contraction with the initial rise of intraventricular pressure by measuring chordae tendineae tension. He interprets his data as indicating that chorda tendinea tension develops at the same time as the initial upstroke of the intraventricular pressure. This would tend to conflict with the data of Puff and Rushmer (14) who teach that the papillary muscle begins contracting before all other ventricular muscle segments. However, Salisbury recorded his data at a paper speed too slow to allow for accurate measurement of the minute time differences which would be expected on such recordings. This is indeed unfortunate because such measurements properly

made with a high speed recording apparatus would contribute much to the present understanding of ventricular synchrony and cardiac dynamics.

In the present investigations, a series of small strain gauge arches in combination with pin electrodes were positioned at several sites on the left ventricle of a number of dogs in an attempt to measure the sequence of mechanical shortening and electrical excitation. The data derived during control periods will be contrasted with that derived during sympathetic stimulation. In this way the above mentioned inferences and presumptions can be tested.

CHAPTER II

MATERIALS AND METHODS

In a group of nine mongrel dogs (6-23 Kg) anesthetized with Nembutal (Pentobarbital Sodium, 32 mg/Kg) a left thoracotomy was performed and the third and fourth ribs removed (Series I). A unipolar electrode was looped around the caudal pole of the left stellate ganglion and a pericardial cradle constructed. Three SR-4 BLH strain gauges (modified Walton gauges) were sutured to the anterior epicardium of the left ventricle with 4-0 surgical silk. All gauges were positioned perpendicular to the interventricular septum (Figure 1), one (No. 1) at the base, a second (No. 2) at the apex and a third (No. 4) approximately midway between the above two. A fourth gauge (No. 3) to be described in greater detail later was plunged into the interventricular septum rather than sutured in position on the epicardium. A segment of approximately 1 cm of myocardium was contained between the points of attachment of each strain gauge arch, and the sutures of gauges Nos. 1, 2, and 4 penetrated to a depth of approximately 3 mm. The relative position of placement of the strain gauge arches as well as their gross design will be noted on Figure 1.

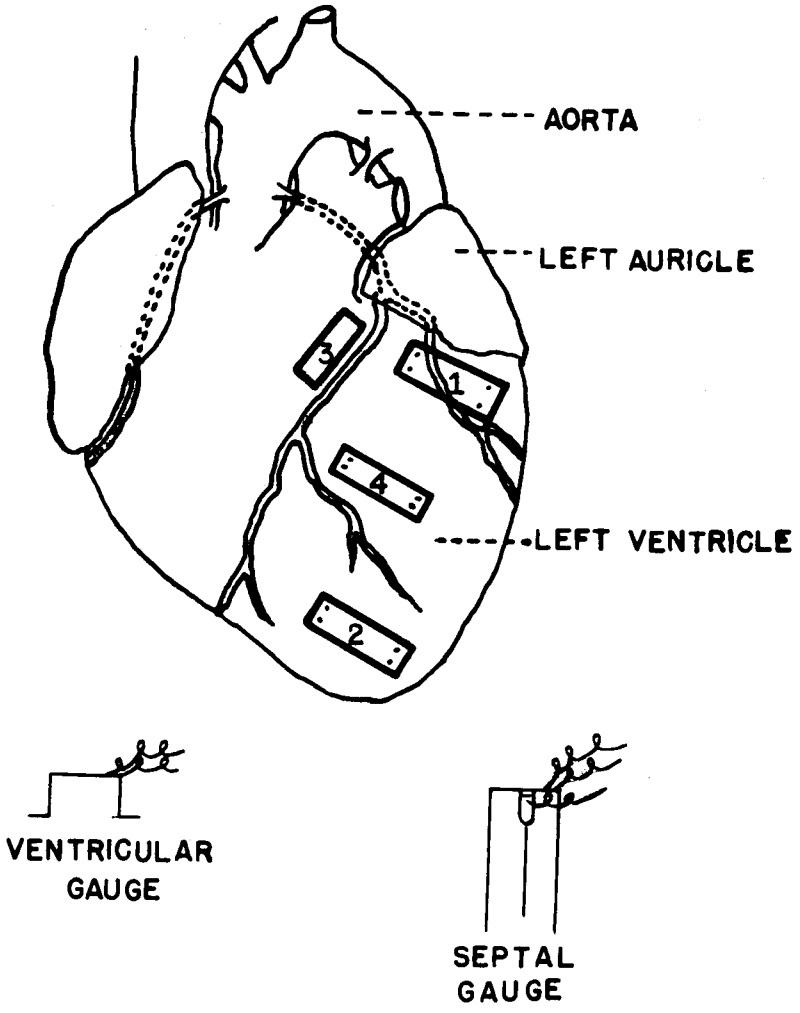

FIGURE 1

SKETCH OF ANTERIOR HEART WITH STRAIN GAUGE ARCH PLACEMENT AND GROSS DESIGN

In a second group of eight dogs (7-21 Kg) anesthetized with chloralose (i.v. 100 mg/Kg), pin electrodes were positioned between the legs of the strain gauge arches to record the simultaneous mechanical and electrical activity in each region. In this second group of dogs (Series II), strain gauge arch No. 4 was not applied to the experimental preparations.

The strain gauge arch used to record activity in the interventricular septum (No. 3) in both Series I and Series II was constructed in an E shape as diagramed in Figure 1. The lateral prongs, which were sharpened and 1.5 cm in length, recorded the mechanical activity while the middle prong served as an electrical pick-up electrode. The latter was insulated from the remainder of the unit with flexible epoxy resin. The prong itself was insulated except for the terminal 1.5 mm with several coats of insulating varnish. The prongs of this unit were pushed through the anterior cardiac wall beside the anterior descending coronary vessels until positioned in approximately the center of the thickness of the interventricular septum at a point approximately 2 cm from the base. At the conclusion of each experiment, the heart was examined to be certain that the legs of the gauge were in the anticipated position. Furthermore, to be certain that only septal activity was recorded by this unit, a right ventriculotomy was performed and the unit directly implanted into the interventricular septum of 3 dogs (Series III). The records so obtained were

compared with all others to rule out artifact in the latter.

Simultaneous recordings of the electrical and contractile events, together with left carotid arterial pulses were recorded on a Grass Model 5A polygraph at a paper speed of 100 mm/sec. during control periods and periods of stellate stimulation. Stimulation was accomplished with a Grass Model S5 isolation stimulator at 10 volts, a frequency of 5/sec. and a pulse duration of 5 msec. Since the proper interpretation of the data to be obtained using the above recording apparatus demanded a rapid response time of that apparatus, it was deemed necessary to measure the response time of the integral recording system. This becomes obvious if one considers that a critical measurement of the type to be presented in this thesis involves the ability of the recording apparatus to rapidly respond by means of a pen deflection to rapid changes in the muscle segment length.

When tension was instaneously released from the legs of a strain gauge arch, the response time before the initial pen deflection was measured to be less than 1 msec. The rise time of the pen deflection was measured to be 7 msec. for 60 per cent of the total amplitude of deflection. The frequency response of the strain gauge arch was determined to be in excess of 250 cps. The frequency response of the polygraph unit itself is linear plus or minus 5 per cent from DC to 45 cps. In view of this, the recording system was considered to be more

than adequate for the type of measurements which were to be made.

CHAPTER III

EXPERIMENTAL RESULTS

Figure 2 shows simultaneous recordings of the left carotid arterial pressure, mechanical shortening of a segment at the base, the apex and the interventricular septum of the left ventricle. Control records are shown at the left and responses to left stellate ganglion stimulation at the right. The epicardial segment at the base was clearly the first area to shorten. It will be noted that in this case the latter is true of both the control record and the record of sympathetic stimulation. Shortening at the apex followed that at the base by 12 msec. in the control and by 5 msec. in the augmentation record while the interventricular septum was the last of the three segments to begin shortening. The onset of shortening of the interventricular septum occured 5 msec. after that at the apex in the control tracing and 3 msec. thereafter in the augmentation tracing. A total of 50 separate measurements similar to those demonstrated on page 11 were made using the 9 animals of Series I. Of these, during control periods, 20 showed initial shortening at the apex, 23 at the base and 7 in the area between the base and apex. The time interval between the on-

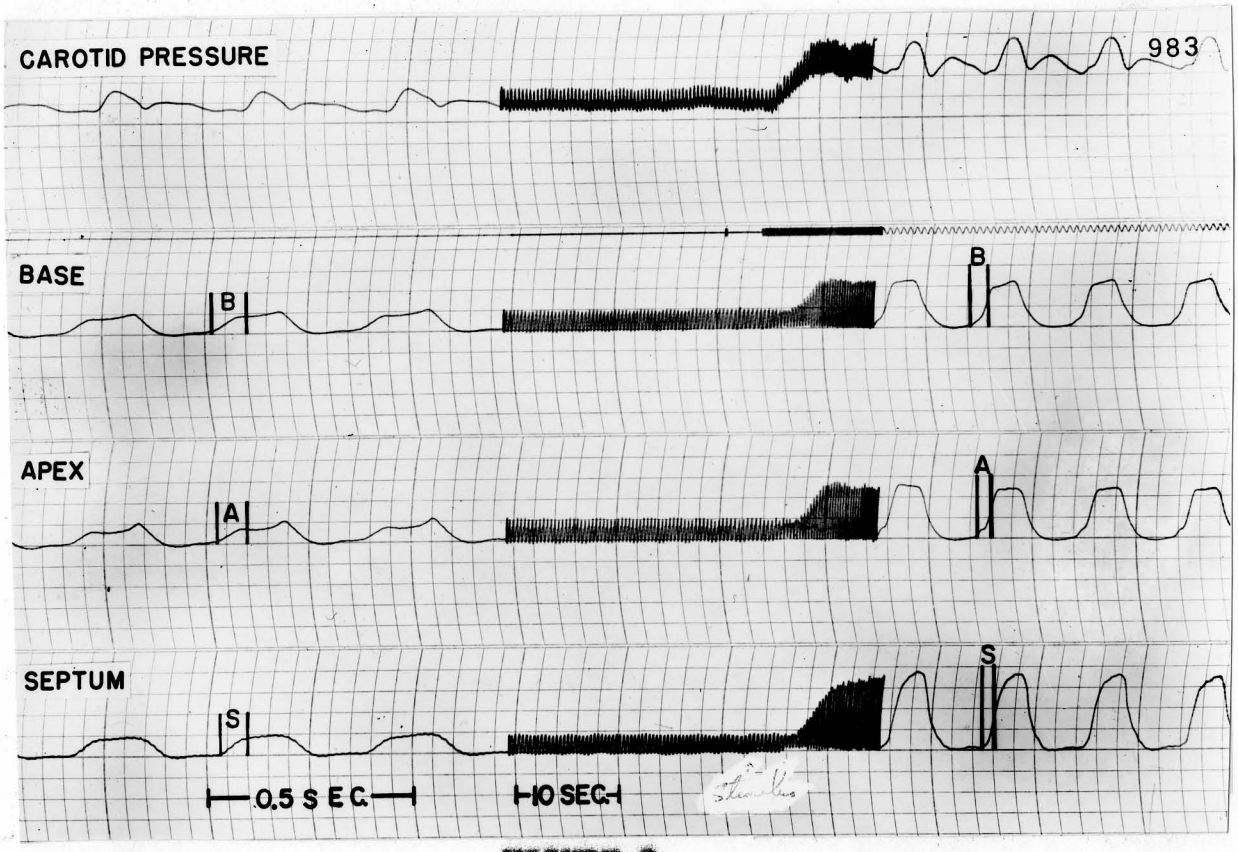

FIGURE 2

SIMULTANEOUS STRAIN GAUGE RECORDINGS
AND LEFT CAROTID PRESSURE PULSE

set of shortening in the first segment to contract and that in the last ranged between 10 and 60 msec. with a mean of 21 msec. Many of the contraction pulses were biphasic showing an initial upstroke followed by a plateau or brief relaxation which was in turn followed by a second upstroke.

All segments in Figure 2 responded to sympathetic stimulation with a marked augmentation in force of contraction, and heart rate increased from 168 to 246 beats per minute. The arterial pressure pulse showed a typical augmentation response with an increase in mean pressure from 125 mm Hg during control periods to 163 mm Hg during stimulation. The fast trace reveals dramatic alterations in the contour of the individual pulses together with the increase in force. To the author's knowledge, this is the first demonstration of augmentation in the force of contraction of the interventricular septum during sympathetic stimulation. The alterations in individual pulse contour include a much more rapid rate of muscular shortening, as well as lengthening or relaxing, together with a reduction in the total duration of the cycle. It is interesting also that a sharp rise in the carotid arterial blood pressure is well established considerably before any alterations in the force of contraction appeared in the test muscle segments. It is clear from this that the strain gauge arches were most likely not positioned on the segments of the ventricular myocardium which most rapidly responds with an increase force of contrac-

tion when a sympathetic stimulus is applied. It is also possible, however, that improved synchrony of contraction of multiple muscle segments could induce a more prompt elevation of intraventricular pressure with little or no alteration in force of contraction by each individual segment.

The intervals designated by the letters B, A and S in Figure 2 represent the time intervals between the onset of shortening in each individual muscle segment and the initial upstroke of the arterial pressure pulse (contraction-pulse interval). The segment shortening first has a longer contraction-pulse interval than those which follow it. Since these intervals possess a common reference point (initial upstroke of arterial pressure pulse), they indicate the sequence of shortening, as well as a measure of synchrony of shortening. The contraction-pulse interval of the base in the control portion of Figure 2 is 75 msec. and that of the septum 57 msec. The difference between these two values is the time interval between initial shortening in the first and last segments, in this case 18 msec. The corresponding values during stimulation are 41 msec. at the base and 32 msec. at the septum for a difference of 9 msec. Thus, by two different measurements (the successive times to onset of muscular shortening, and the contraction-pulse interval) it is clear that these three separate muscle segments contracted more synchronously during left stellate ganglion stimulation.

Whereas the strain gauge arch fixed to the muscle segment at the base of the heart showed initial shortening in approximately one half of the fifty control traces, it revealed initial shortening in 49 of the 50 traces during sympathetic stimulation. The interval between the onset of shortening in the first area to contract and the last to contract during stellate stimulation ranged between 2 and 35 msec. with an average of 12 msec. as compared with an average of 21 msec. during control periods.

In figure 3 both the electrical and the mechanical activity are illustrated at the interventricular septum, the apex and the base of the left ventricle. The carotid arterial pressure is also shown. Sequential patterns of electrical excitation and mechanical shortening were determined, and coupling times between the electrical excitation and onset of mechanical shortening were measured. While the sequence of electrical excitation in the control trace (left portion of Figure 3) compared favorably with the results obtained by Harris (4) and by Wiggers (27), the sequence of mechanical shortening did not follow the same sequential pattern. Due to the location of the active portion of the septal gauge in approximately the center of the thick muscle mass of the septum, considerable deviation from the time of excitation at the septal endocardium is to be expected. In many experiments electrical excitation in this portion of the septum occured several millisec-

onds after it occured at the other recording points on the apex and base.

In the control portion of Figure 3, electrical activity appeared first at the septal electrical recording point, approximately 5 msec. later at the apex electrode and 10 msec. later at the base electrode. The interval between electrical excitation and mechanical shortening (electro-mechanical coupling time) was 30 msec. at the septum, 25 msec. at the apex and 20 msec. at the base. Comparable data derived from pulses recorded just a few seconds later, but during stellate stimulation, show that electrical activity first appeared at the base electrode, followed 10 msec. later by activity at the apex and 15 msec. later at the septal electrode. These observations are shown on the figure on page 16 by a horizontal line extending from the simultaneous ordinate on each of the electrical activity traces. In both the control and the stimulation portions of the record, the time interval from the ordinate to the initial deflection of the electrical trace of the base electrode was laid off, and an identicle line drawn beneath the traces of apex and septal activity. In the control records the base excitation clearly followed both apex and septum. However, in the stimulation record it clearly preceeded both. Coupling times during stimulation were 25 msec. at the septum, 15 msec. at the apex and 8 msec. at the base. Thus, it is clear that the sequence of initial excitation was altered signi-

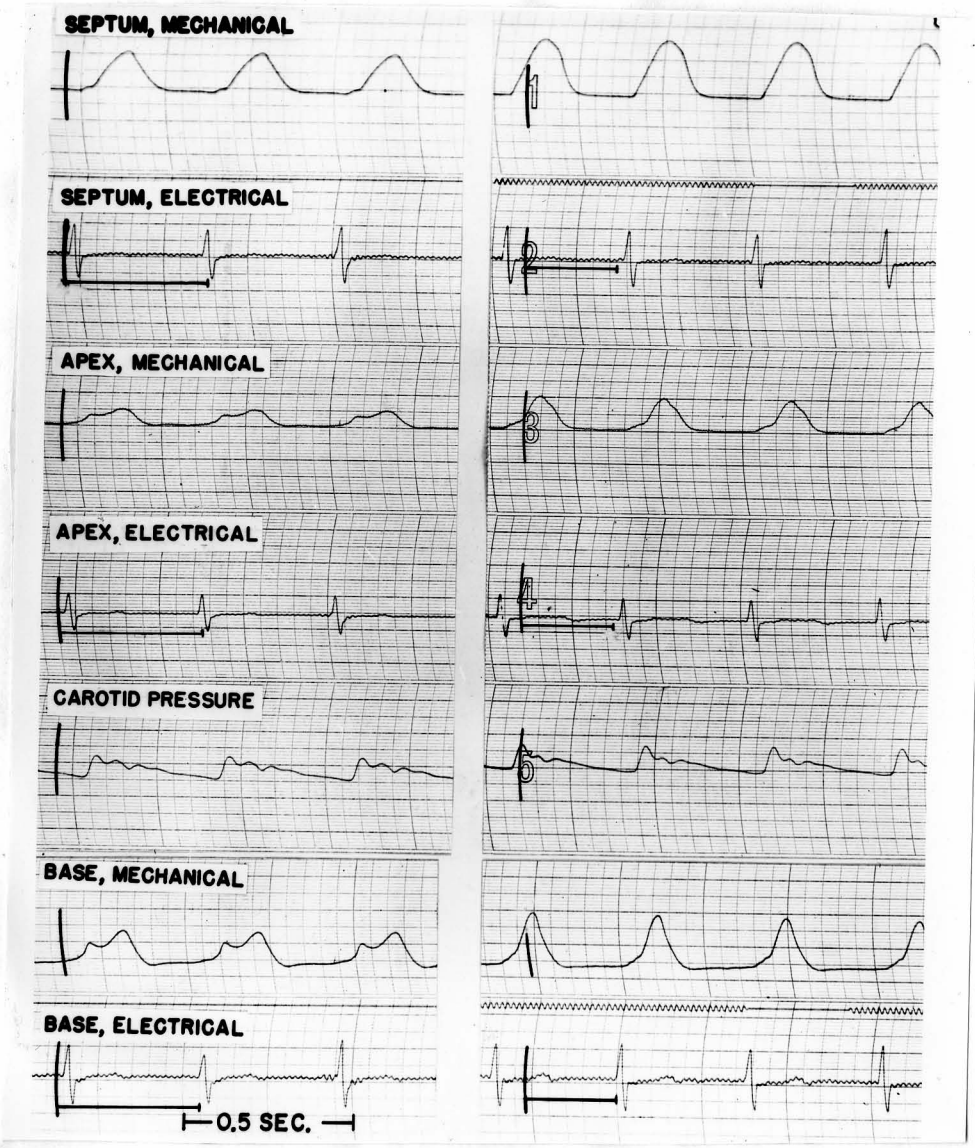

FIGURE 3

SIMULTANEOUS MECHANICAL AND ELECTRICAL ACTIVITY AND LEFT CAROTID PRESSURE PULSE

ficantly during sympathetic stimulation, and the electro-mechanical coupling time at the base markedly shortened. The latter observation was invariable at the base but not at the septum where data from all experiments reveals an average lengthening of the electro-mechanical coupling time from 25 msec. in the control state to 34 msec. during stellate stimulation. As illustrated in Figure 2, the interval between the onset of shortening in each specific myocardial segment and the upswing in carotid pressure decreased significantly during stellate stimulation. It is also clear that marked augmentation in force of contraction occured in each of the segments during stimulation. Careful observation of the individual pulse contour before and during stimulation reveals important changes, particularly in the apex and base regions. Whereas both of these regions show biphasic curves in the control portion of the figure, this is considerably less evident during left stellate ganglion stimulation. The onset of contraction is generally sharper and much more easily determined during stellate ganglion stimulation than during the control periods.

Table I on page 18 presents in a tabular fashion a summary of the data obtained from Series I and Series II groups of animals. The horizontal column representing Series III will be commented upon in the following chapter. It should be noted from the table that the Contraction-Pulse Interval is greatest at the base of the ventricle and least at the interventricular

TABLE I

CONTRACTION-PULSE INTERVALS AND ELECTRO-MECHANICAL COUPLING TIMES

		CONTROL				STELLATE STIMULATION				Number of Animals
		Septum	Apex	Base	Heart Rate	Septum	Apex	Base	Heart Rate	
Contraction Pulse Interval in msec	Average of 50 measurements	52	70	73	140	32	37	44	168	9
	Range	12 - 100	18 - 110	60 - 114	100 - 188	10 - 60	14 - 69	18 - 82	132 - 258	Series I
	Average of 24 measurements	51	67	71	138	34	40	46	164	8
	Range	10 - 110	13 - 120	30 - 122	114 - 220	10 - 60	12 - 62	15 - 82	126 - 220	Series II
	Average of 6 measurements	50	63	73	183	26	32	37	192	3
	Range	12 - 96	22 - 98	48 - 106	138 - 210	12 - 50	14 - 46	26 - 48	140 - 218	Series III
Electro-mechanical Coupling Time in msec	Average of 24 measurements	25	30	34	138	34	36	25	164	8
	Range	5 - 58	5 - 60	20 - 53	114 - 220	24 - 62	13 - 40	10 - 38	126 - 220	Series II

septum. This is true in both the control and the stimulation sets of data. The average difference between the Contraction-Pulse Intervals of the base and the septum is 21 msec. in the control data of Series I, 20 msec. in Series II and 23 msec. in Series III. The respective average data during stellate ganglion stimulation is 12 msec., 12 msec. and 11 msec. The Electro-Mechanical Coupling Time of the interventricular septum increases from an average of 25 msec. in the control to 34 msec. in the stimulation data. A similar increase occurs at the apex. However, the average Electro-Mechanical Coupling Time of the base decreases from 34 msec. in the control to 25 msec. in the stimulation data.

Because of the large number of measurements which were made, only the averages and the range of spread of the individual measurements could conveniently be included in Table I. However, the data was subjected to statistical methods and the differences noted in the table were shown to be significant with the P never exceeding 0.04.

CHAPTER IV

DISCUSSION OF RESULTS

To the author's knowledge, multiple recordings of shortening in individual myocardial segments have not previously been analyzed in the manner reported here. The author is well aware of certain essential precautions in the use of, as well as the hazzards in interpretation of, data derived from strain gauge arches stitched to the epicardium (2,3). Strict attention was paid to the firm attachment of each limb of the arch to muscle, and effort was made to apply the strain gauge arch in the same relative positions on each heart. It is emphasized also that no attempt was made to quantitate or compare force of contraction in different hearts. Attention is directed, however, to alterations in consecutive traces in a given experiment before, during and after stellate stimulation. Alterations occur within a period of a few seconds as a result of the experimental procedure, and traces progressively return to control configurations following cessation of the procedure. Thus, we have considerable confidence in the reliability of the records presented. In spite of the obvious technical difficulties in separately but simultaneously recording contractile phenomena in several different myocardial segments, the significance of

such measurements once completed compelled this investigation.

The ventricular wall is composed of three basic layers of muscle fibers (14). The central, or constrictor layer, is a thick muscle mass bounded internally by a thin obliquely oriented layer of endocardial muscle fibers and externally by another oblique layer of epicardial muscle fibers. The two oblique layers are oriented approximately 90° to one another in the plane of the ventricular surface. The fibers of the constrictor layer lie at approximately 45° with the oblique layers in this plane. The individual layers show much intermingling of fibers, and they are, hence, not as distinct as might be inferred from the above description. It is understandable, then, that when strain gauge arches are sutured to the epicardium as was done here, the record represents the summation of total vector forces between the points of attachment of the arch. Furthermore, it is conceivable that rotation of the strain gauge arches to a position parallel to the interventricular septum would produce records different from those reported here. The latter applies also if the arches were to be applied by means of deep penetrating sutures.

Although the endocardial surfaces of the septum are undoubtedly the first regions of the ventricle to be excited, considerable time may elapse before the interior muscle mass of this structure is activated. Hence, it is understandable that the septum was the last of the units to show gross shorten-

ing. This explanation can be amplified by the further observation that most experiments show an increase in the coupling time at the septum during stellate stimulation with a concomitant decrease in coupling time at the other test areas. This suggests a preferential modification in excitability of individual contractile elements during sympathetic stimulation, presumably related to a differential distribution of postganglionic terminals in heart tissue.

Further investigation was deemed necessary to rule out the possibility that the late excitation and subsequent shortening of the interventricular septum observed during the course of the experiments comprising Series I and Series II was artifact. When a right heart by-pass pump was utilized and the right ventricle incised so as to expose the interventricular septum, the septal gauge was directly implanted into the septum of three dogs (Series III), and the results obtained showed time intervals identicle to those obtained by the methods described in the previous chapters. Thus, the records presented in the foregoing chapters of this thesis can be attributed to the activity of the interventricular septum and not to the activity of the anterior myocardium through which the septal gauge unit was plunged in Series I and Series II.

The initial shortening at the epicardial surface of the base of the left ventricle in approximately one-half the control measurements was surprising since this is generally pre-

sumed to be the last portion of the heart to be excited (4, 22). A plot of ventricular epicardial potentials (11, 27) reveals the earliest excitation occurs in the center of the trabecular region on the anterior surface. Surrounding this region are points successively activated and extending down toward the apex with simultaneous, but apparently slower extension toward the base. The biphasic nature of the contraction waves (Figures 2 and 3) frequently suggested that one portion of the base shortened early while another portion began to shorten much later in the cycle. A few experiments, in which two strain gauge arches were placed on the base, one close to the septum and the other at the same level but 2 cm lateral to it have tended to confirm this observation. Huff (12) has photographed the normally beating heart at 1,000 frames per second and subsequently projected the film at 24 frames per second, thus achieving a 40-fold slow motion reproduction. In this manner, he described initial contraction of the inflow tract followed by contraction of the outflow tract of the ventricle. In view of these observations, the observations noted earlier in this thesis that the interventricular septum is the last of the segments tested to shorten is quite reasonable. The septum composes the medial wall of the outflow tract and, thus, can be expected to begin contraction after muscle segments which lie lateral to it and in the ventricular inflow tract.

It is probable that one limb of the epicardial strain

gauge arches was fixed on the inflow tract while the other was attached to muscle composing the outflow tract, thus resulting in biphasic contraction waves revealed in many of the traces. If this proves to be true, the tendency for the disappearance of the biphasic contour during stellate stimulation can be interpreted as additional evidence for improved ventricular synchrony with sympathetic stimulation.

As suggested by Sarnoff (19), pressure in the heart is produced by the sequential and progressive development of tension in certain portions of the myocardium while other portions remain uncontracted. When each of the myocardial segments contract independently of any programed sequence, little or no external work is accomplished. On the contrary, when the myocardial fibers contract more nearly synchronously, external work should be inhanced. This is not to argue that all portions of the ventricular musculature will achieve an ultimate peak of efficiency when they contract simultaneously. Indeed, such an explosive development of tension would not accomplish the purposes for which the ventricle was designed. However, the present observations document the inference that the various portions of the ventricles do contract more synchronously, and such phenomena undoubtedly contribute to the more rapid rise and fall, together with higher maximal pressures attained during sympathetic stimulation.

Conduction velocities between two recording electrodes

have been shown to be increased in both atria and ventricles, as well as across the A-V junction, as a result of electrical stimulation of the sympathetic cardiac nerves and by injection of either l-norepinephrine or l-epinephrine (1). Apparently, however, velocity is not markedly increased in the specialized conducting tissue by norepinephrine nor by stellate stimulation (25, 26). Thus, modest changes in the synchrony of contraction of distant portions of the myocardium may be accounted for on the basis of altered conduction velocities. However, the dramatic and consistant shift of initial excitation to the base of the heart cannot be accounted for in this way. There seems to be no alternative to the assumption that the exciting impulse "short-cuts" by some alternate "preferential" pathway to this area during stellate stimulation. On the basis of the data presented in the foregoing chapters, it cannot be ruled out that the early electrical excitation at the ventricular base was associated with an ectopic focus of nodal activity. Indeed, it has been observed by the author that when the stellate ganglion is stimulated in non-vagotomized dogs shuh as those used in this investigation, the ECG shows evidence of ectopic nodal activity more frequently than in vagotomized preparations. The location of "preferential pathways" from nodal tissue to the base of the ventricles is not clear, but such channels seem to be opened through nervous stimulation, perhaps through local liberation of norepinephrine. Kent reported that the A-V node

and its Purkinje branches are not the only connection between the atria and ventricles. He described accessory conduction pathways composed of ordinary myocardial cells, the "Bundle of Kent" (8), but more recently Mistin was unable to confirm these observations (9). Discrete anatomical accessory pathways have, however, been described in the human heart in patients who manifest Wolff-Parkinson-White Syndrome (10).

During control experiments, the time interval between the onset of shortening in the first area to contract and the interventricular septum, which was the last area to begin shortening, varied between 10 and 60 msec. with an average of 21 msec. During left stellate ganglion stimulation this time interval decreased to an average of 12 msec. with a range of 2 to 35 msec. Thus, as previously inferred (16, 24), left ventricular contraction becomes more nearly synchronous during stellate stimulation. This undoubtedly contributes to the more rapid rise phase of the ventricular pressure pulse during such electrical stimulation (18).

The shortening of the various segments of the left ventricle in this group of experiments occurs at a time in the cardiac cycle which would correspond to a combination of the apex-to-base shortening and the change in cross-sectional area as reported by Hawthorne (5). This indicates that the methods employed in the present study are non-specific as regards the direction of the dimensional changes of the ventricle, but they

test rather the sequence of shortening, either apex-to-base and/or circumferential, in the various segments of the ventricle and the modification of this sequence during sympathetic augmentation.

CHAPTER V

SUMMARY

Until this time no direct measurements of the synchrony of shortening of individual myocardial muscle segments have been available. There have been, however, as noted in the previous chapters, a number of inferences put forward in the scientific literature which suggested that the heart normally functions in an asynchronous fashion. Furthermore, it has been speculated that a modification of the synchrony of myocardial contraction could explain some phenomena associated with sympathetic augmentation. Katcher and his associates demonstrated by means of cinematography that the ventricle contracts more nearly synchronously following the injection of levarterenal. Such a photographic demonstration, however, is not subject to careful quantitative examination of the time intervals between the onset of shortening in various myocardial segments and, hence, is not entirely adequate to substantiate the inferences which were made.

The primary purpose of the research incorporated into this thesis has been to document the synchrony concept of ventricular dynamics as being true or false. It has been shown in the

foregoing chapters that the myocardial segments do, indeed, normally shorten in an asynchronous fashion. During left stellate ganglion stimulation, the muscle segments tested began shortening in a much more predictable, as well as synchronous manner. It should also be emphasized that to the author's knowledge an analysis of the interventricular septum such as has been presented in this thesis, has never been presented. Furthermore, excepting Ruff's photographic evidence, the above analysis is the first to tentatively suggest the early contraction of the ventricular inflow tract followed by the contraction of the outflow tract.

The measurements of the sequence of electrical excitation of ventricular segments presented in this thesis agree, at least in the control state, with those of numerous other investigators. During the period of sympathetic stimulation a peculiar pattern of impulse spread was frequently noted. Such patterns disclosed the early appearance of the electrical potential at the base of the ventricle followed by its appearance in the other segments. This was interpreted as evidence for the existence of "preferential" pathways of conduction. Since no electrocardiogram was recorded, the possibility of an ectopic focus of nodal activity within the ventricle could not be definitely ruled out.

In conclusion, by means of providing significant evidence for what were hitherto tentative suppositions, the primary pur-

pose of this investigation has been fulfilled. In addition to the fulfillment of the primary goal, several unpredicted entities were serendipitously recorded and later discussed.

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APPROVAL SHEET

The thesis submitted by Charles E. Osadjan has been read and approved by three members of the faculty of the Graduate School.

The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated, and that the thesis is now given final approval with reference to content, form and mechanical accuracy.

The thesis is therefore accepted in partial fulfillment of the requirements for the Degree of Master of Science.

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