Electrical and Mechanical Properties of Chick Embryo Heart Chambers

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Electrical and mechanical events of the atrium, ventricle and conus of the 72-hour chick embryo heart were recorded by a specially designed instrument. The electrical-mechanical delay and the time of muscular contraction differed among the chambers, the atrium being the most rapid and the conus, the slowest. Muscular relaxation times of the atrium and ventricle were approximately one-half that of the conus. Mechanical performance, gauged by the approximations of work and power, was greatest for the ventricle, but based on the muscle mass (protein), values for the ventricle and conus were similar. Electrical activation of the ventricle followed a consistent pathway, suggesting the existence of a preferential conduction system prior to the development of the His bundle.

The chick embryo heart is well suited for the study of myocardial function and metabolism. The electrocardiogram of the intact chick embryo and of the isolated heart has characteristics similar to the hearts of phylogenetically more advanced species.1-5 Embryonic tissue, such as that obtained from the 72-hour chick, in addition to its ready availability has the further advantage that there is no coronary circulation, and fluid, electrolytes and metabolites diffuse directly into the myocardial fibers and cells.

The small size of this tissue limits the practicability of its use for the direct observation of fine movement details. This report describes an instrument for the simultaneous recording and analysis of the electrical and mechanical events of the chick embryo heart in each of the three chambers.

METHODS

The heart was removed from the 72-hour chick embryo and placed in Tyrode solution; the venous inflow and aortic arches attachments were transected to avoid myocardial injury. After inspection to determine age and activity, the heart was placed in a drop of a 1:1 mixture of Tyrode solution and chicken plasma on a glass slide.

The sensing element is a light, dual purpose platinum lever, one end of which rests on the heart (fig. 1). The second or indifferent probe rests in the plasma drop which supports the heart and serves to complete the circuit for the electrocardiogram.

The original electrocardiographic signal is small in comparison with the signal observed in man. Therefore, a two-stage triode push-pull amplification is interposed between the pickup and the recorder amplifier. A gain of 400:1 is attained so that with a recorder with a sensitivity of 1 mv./cm. a total sensitivity of 2 μv./cm. may be realized. A thermal and electrical shield around the pickup and a circuit with an inherent low noise level permit a stable, interference-free recording of the chick heart electrocardiogram.

The opposite end of the lever is isolated electrically from the probe and its motion serves to indicate the physical activity of the heart (fig. 1). A differential capacitance sensing circuit operates from a pair of fixed capacitor plates excited in equal and opposite phase by a 30-kc. oscillator. The movable plate (the lever) picks up a 30-kc. signal of phase and magnitude relative to its position between these plates. This signal is identified and amplified in proportion to its magnitude and phase and is then recorded simultaneously with the electrocardiogram on dual trace paper using a direct writing Sanborn recorder.

The heart was always positioned in the plasma clot in the same manner and the sensing arm placed in the same location on the atrium, ventricle or conus. When records of the ventricle...
CHICK HEART MOUNT
(Top View)

FIG. 1. Apparatus for sensing electrical and mechanical properties of the chick embryo heart.

were taken, the sensing arm was placed midway on the ventricle. Records of isolated chambers were obtained from hearts which were transected at the atrioventricular and ventriculoconal junctions after the heart had been fixed in position by the plasma clot.

To obtain records of hearts with intact circulatory systems, the embryo was removed from the egg and placed on a glass slide. A small amount of the ectoderm overlying the heart was removed and records were taken for the ventricle and atrium.

Approximate values of work and power for the chambers were obtained by recording the movement of a weight (1.96 mg. sensing arm) over a distance (height) in a period of time (recording paper). These approximations were not representative of total work or power since displacement of the sensing arm was in one direction only. Furthermore, the work performed against the plasma clot was not included in the calculation.

In the analysis of the electrocardiograms, the conduction times were measured from the records obtained with fast paper speed (50 mm./sec.). The existence of a standard conduction pathway was investigated by partial transection of the atrioventricular groove in either direction. Ventricular conduction was studied by cutting interdigitation wedges along the ventricular musculature.

Electromechanical phenomena were followed by measuring the time between the onset of electrical activity and the beginning of contraction (fig. 2). The time required for contraction and relaxation was measured directly from the records.

Atria, ventricles and coni were obtained by transection of 24 hearts and protein content of the chambers was determined. The tissues of each chamber were combined and digested by the standard micro-Kjeldahl method. Nitrogen was determined by the microdiffusion technic of Conway and converted to protein by the conversion factor of 6.25.

The ambient temperature was maintained at 29 ± 1 C. by a thermostatically controlled heating unit within the shielding cabinet since temperature control is essential for the development of comparable records.

RESULTS

The mechanical properties of the ventricles and coni of 27 isolated intact 72-hour chick embryo hearts were analyzed. The only property of the atrium which could be measured was the electromechanical delay because the effects of the ventricular contraction distorted the atrial myogram. Since isolation of the atrium by atrioventricular transection caused no obvious change in its activity, the other
Physiologic Properties of the Chick Embryo Heart

Table 1.—Electromechanical Properties of Chick Embryo Heart

<table>
<thead>
<tr>
<th></th>
<th>Time in seconds</th>
<th>Power (mm. mg.)</th>
<th>Work (mm. mg.)</th>
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<tbody>
<tr>
<td>Atrium</td>
<td>.029 ± .002*</td>
<td>.12 ± .004</td>
<td>.18 ± .008</td>
</tr>
<tr>
<td></td>
<td>± .003</td>
<td>± .013</td>
<td>± .013</td>
</tr>
<tr>
<td>Ventricle</td>
<td>.035 ± .002</td>
<td>.16 ± .005</td>
<td>.194 ± .008</td>
</tr>
<tr>
<td></td>
<td>± .006</td>
<td>± .005</td>
<td>± .006</td>
</tr>
<tr>
<td>Conus</td>
<td>.10 ± .006</td>
<td>.34 ± .012</td>
<td>.087 ± .008</td>
</tr>
<tr>
<td></td>
<td>± .012</td>
<td>± .013</td>
<td>± .008</td>
</tr>
</tbody>
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* Mean and standard error of the mean.

Mechanical properties of the atrium were derived from the study of 18 isolated atrial preparations (table 1).

Electromechanical delay varied significantly among the chambers; the atrium consistently had the shortest time lag. The delay was so characteristic for each of the chambers that failure to section the ventriculoconal area properly could be detected by the shortened time interval and the altered myogram, which represented a blend of the ventricular and conal muscular contraction. Atrial muscular contraction was more rapid than that of ventricular contraction, which was faster than that of the conus. The relatively slow movements of the conus muscle were reflected in the prolonged relaxation time (.34 sec.). Time for muscular relaxation was the same for the atrium and ventricle.

Mechanical performance, gauged by the approximation for work (mm. mg.) and power (mm. mg./sec.), differed in the three chambers. The greatest amount of work and power was developed by the ventricle. When these values were expressed on the basis of the amount of protein, the performances of the ventricle and conus were similar (table 1).

Contraction of the ventricle resulted in similar myograms from the mid- and conal-ventricular regions. The electrocardiogram of the chick heart was of a unipolar nature; the indifferent electrode was placed at a distance from the heart which did not contribute to the tracing. It was composed of a distinct P-wave, P-R interval, QRS complex and the T-wave (fig. 3). Records from the isolated hearts were similar to those obtained from the hearts in vivo. Electrical and mechanical records from the atrium, ventricle or conus were easily recognizable by their distinctive features (fig. 4).
When the sensing electrode was placed midway on the ventricle, the initial electrical force in 27 intact hearts was directed toward the electrode, inscribing an initial R-wave on the electrocardiogram; the dominant force was in the opposite direction, producing a deep S-wave. The placement of the sensing arm on the ventricle near the atrium recorded principally an S-wave. At the outflow end of the ventricle, the record was chiefly an R-wave (fig. 5).

Complete transection of the heart at the atrioventricular and ventriculoconal areas resulted in idioatrial and idioventricular rhythms. Idioconal rhythms were rarely observed and, when present, were slower than the idioventricular rates. Atrial contraction appeared to be similar to that of the intact hearts; however, ventricular behaviour was markedly different in the two preparations. In the intact hearts, the rate was 82/min., whereas idioventricular rates were 22/min. Electromechanical delay for the atrium and ventricle of the completely transected hearts was similar to that of the intact preparations.

Isolated conal tissue differed in its rhythmic properties from the isolated atrium and ventricle. When idioconal electrical impulses developed, the rate was exceedingly slow and rarely resulted in a mechanical response. When the mechanical response occurred, it had the same electromechanical delay as the intact conus. Conal electrocardiograms were bizarre, i.e., prolonged conduction times and slow repolarization time.

Partial transection through the atrioventricular sulcus at the greater or lesser curvature of the heart produced a significant increase in atrioventricular conduction time; mean value for 10 records was 0.12 ± 0.008. Intraventricular conduction was also significantly prolonged by the partial atrioventricular transection. The prolonged atrioventricular conduction time was somewhat more prominent when the section was made through the lesser curvature. The ventricular electrocardiograms resembled those of the intact heart when the greater curvature portion was partially transected while a striking difference occurred with the incomplete transection through the lesser curvature (fig. 6).

Partial transection of the ventricle at three different sites caused an increase in the intraventricular conduction time (.03 sec.), which
was no greater than that observed when the sectioning had been made in the atrioventricular sulcus. Multiple incisions in the ventricle caused a reorienting of the electrical forces (fig. 6).

**DISCUSSION**

The three chambers of the 72-hour chick embryo heart have properties other than the variations in the intrinsic rhythms observed by previous investigators. Variations in the electromechanical delay, contraction and relaxation times, and work and power approximations and the sluggishness of the conal area may be related to differences in the membrane permeability, to the physicochemical union of the contractile proteins or to the metabolic processes and their biochemical energetics.

Depolarization in the atrium, ventricle and conus was followed by mechanical activity. However, the electromechanical delay differed in the three chambers; the atrial mechanical response occurred less than .03 sec. after depolarization while the conus reacted like the “slow” muscle fibers which have been described in the skeletal muscles of the frog. Transection of the ventriculoconal junction or multiple incisions in the ventricle resulted in occasional electromechanical dissociation in the conus, i.e., the recording of an electrical event without a resultant mechanical contraction. Usually, the electrical event which failed to induce a muscular response was weaker than the effective electrical impulse. It has been suggested that the coupling of electrical and mechanical activities is related to membrane depolarization and ion shift. If this were true, the electromechanical differences in the three chambers may be the result of variations in membrane potential and ionic permeability.

The progressive lag in the electromechanical response and in the duration of contraction of the three chambers serves to facilitate the pumping action of the tubular heart (fig. 7). The short brisk atrial activity is completed as the ventricular contraction commences and the sluggishness of the conus effects a patent outflow tract while the ventricle is emptying. The prolonged conal contraction produces a
sphincter-like closure of the outflow tract at the end of systole. Thus, without valves, little regurgitation of blood occurs.

The electromotive force which activates the mechanical properties of the chambers is predictable in its duration. A pacemaker, located in the upper portion of the atrium, controls the rate and rhythm of the heart. Following the passage of the electrical impulse over the atrium to produce the P-wave of the electrocardiogram, a pause occurs before its entrance into the ventricle. This delay, the P-R interval, has been classically ascribed to the refractoriness of the atrioventricular node. However, no recognizable nodal tissue exists in the 72-hour chick embryo heart. Perhaps the ventricular muscle has a prolonged refractoriness caused by an unknown mechanism which results in the atrioventricular conduction delay.

The electrical activation of the ventricle may occur anywhere along the atrioventricular junction. However, in the majority of records, electrical excitation followed a preferred pathway which was located at the atrioventricular area near the lesser curvature of the heart. From this area, the remainder of the ventricle is activated (fig. 5). Conal activation then follows. This repetitive record of electrical forces strongly suggests a conduction pathway for the embryonic heart, a pathway which operates prior to the development of the bundle of His. From this area, the remainder of the ventricle is activated (fig. 5). Conal activation then follows. This repetitive record of electrical forces strongly suggests a conduction pathway for the embryonic heart, a pathway which operates prior to the development of the bundle of His. In mammalian hearts, the anlage of the His bundle is found near the crest of the developing ventricular septum. No ventricular septum is present in the 72-hour chick embryo heart. Further evidence for the embryonal conduction pathway was seen in partial atrioventricular transection. As long as atrioventricular continuity existed in the region of the lesser curvature, a small R-wave followed by a large S-deflection occurred, and this resembled the record of the intact heart.

**SUMMARY**

An instrument has been developed which permits investigation of the electrical and mechanical events of the atrium, ventricle and conus of the 72-hour chick embryo heart. The electrical properties are as follows: The pacemaker is located high in the atrium. Atrioventricular delay occurs in the absence of nodal tissue. A preferential pathway of ventricular conduction antedates the development of the His bundle.

The mechanical properties are as follows: Electromechanical delay and contraction time are shortest in the atrium and longest in the conus. Relaxation time is similar in the atrium and ventricle and approximately one-half that of the conus. Based on muscle mass (protein), the ventricle and conus have comparable work and power approximations.

**ACKNOWLEDGMENT**

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**SUMMARIO IN INTERLINGUA**

Esseva disveloppate un instrumento que permitte le investigation del eventos electric e mechanic in le atrio, le ventriculo, e le cono in le corde de embryones de gallina de 72 horas de etate. Le proprietates electric es le sequentes: Le pacemaker es le sequentes: Le pacemaker es locate alte in le atrio. Il occurre un retardo atrioventricular a causa del absentia de histo nodal. Un via preferential de conduction ventricular precede le disveloppamento del fasce de His.

Le proprietates mechanic es le sequentes: Le retardo electromecanic e le tempore de contractiones le plus breve in le atrio e le plus longe in le cono. Le tempore de relaxation es simile in atrio e ventriculo. In le cono, illo es aproximativemente duo vices plus longe. Calculate super le base de massa muscular (proteina), le ventriculo e le cono ha aproximativamente le mesme carga de labor e le mesme potentia.

**REFERENCES**


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