Systolic Time Intervals in Infants with Congestive Heart Failure

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SUMMARY
Using the apexcardiogram as a time reference for opening and closure of the aortic valve, systolic time intervals (STI) in infants were determined in 150 normal infants ranging in age from 1 day to 1 year. Thirty infants with congestive heart failure secondary to a variety of congenital and acquired heart diseases were studied in a similar manner for comparison. The data revealed that heart failure in the infant is not marked by any one pattern of STI. In specific disease entities associated with congestive heart failure, the STI appear to be consistent.

In infants with congestive heart failure due to congenital heart disease, the STI do not correspond with values reported in the adult with hypertensive or arteriosclerotic disease. The differences are explained by viewing STI in infants primarily a function of hemodynamic alterations dictated by an underlying cardiovascular anomaly rather than a result of a primary myocardial derangement. The findings in the infant with chronic heart failure due to primary myocardial disease tend to parallel data previously reported in the adult with arteriosclerotic disease and chronic heart failure.

Additional Indexing Words:
Apexcardiography  Congenital heart disease  Myocardial disease

SYSTOLIC TIME INTERVALS have been the focus of an extensive literature in the past decade, a comprehensive review of which has recently been published by Weissler and co-workers. The relationship between time intervals during systole and cardiac performance or functional hemodynamic status has been systematically studied and from these correlative studies a useful clinical tool has emerged.

Published data on systolic time intervals are available for the normal adult and also for a variety of disease states in the adult. Similar data in infants, however, is only fragmentary. Technical difficulties encountered in the recording of indirect central arterial pulse tracings in the infant is largely accountable for this paucity of data. However, the graphic recording of low-frequency precordial movements referred to as apexcardiography, affords an opportunity in the infant for identifying those intracardiac events which are ordinarily obtained from an indirect carotid pulse tracing in the adult.

The apexcardiogram in the infant has been observed to depict specific events in the cardiac cycle with a degree of accuracy not usually achieved in the adult. Low-frequency pulsations transmitted from the heart to the chest surface traverse an obviously thinner tissue barrier in the infant than in the adult, generally resulting in a minimum of surface damping and delay.

Systolic time intervals were accurately measured in infants with and without heart disease from the simultaneous recording of the apexcardiogram, phonocardiogram, and an appropriate electrocardiographic lead. The investigation was designed to establish standards for infants with normal cardiovascular function. In addition, infants in congestive heart failure, as determined by commonly accepted clinical criteria, were similarly studied and the values obtained were compared to those in the normal infant and to published data on systolic time intervals in heart failure in the adult.

Materials and Methods
In 150 normal infants, between 2 hours and 1 year of age, the apexcardiogram, phonocardiogram, and a
selected electrocardiographic lead were recorded simultaneously. The electrocardiographic lead selected was the one that most clearly demonstrated the onset of ventricular depolarization (Q wave). Lead II was the lead most frequently recorded. Infrequently, where a distinct Q wave was not seen, it was necessary to record two simultaneous leads in order to ascertain the precise onset of depolarization. The apexcardiogram was recorded with a microphone (Electronics-for-Medicine model PS-1B) which was hand held at the point of maximum cardiac impulse. Almost invariably, the point of maximal impulse in the normal infant was in the fourth left intercostal space just lateral to the lower left sternal margin. The phonocardiogram was obtained with a second microphone (model PS-1B) fixed with tape over the second left intercostal space. The sound was filtered so that the high-frequency components of the first and second heart sounds were easily visualized. All recordings were made with subjects unsedated, but quiet and in the supine position. The tracings were recorded on an optical recorder (Hewlett-Packard no. 500 multichannel). The paper speed was set at 100 mm/sec and time lines were inscribed at 0.04-sec intervals. If the apexcardiogram failed to display the E point and the incisural notch with point-sharp clarity, or if the systolic intervals, for whatever reason, were not accurately measurable to within 5 msec, the records were discarded. Less than 10% of our records were rejected on this basis.

Figure 1 is a diagram illustrating the simultaneous inscription of the proximal aortic pressure pulse, apexcardiogram, phonocardiogram, and electrocardiogram. The point of onset of the Q wave in the electrocardiogram to the point identified as the E point in the apexcardiogram was designated as the prejection period. Left ventricular ejection time was the measured time interval between the E point and the incisural notch on the apexcardiogram. The incisural notch corresponded in time to the first high-frequency component of the aortic component of the second heart sound. The onset of the Q wave to the dicrotic notch was regarded as the time of total electromechanical systole.

In 17 infants, studies were performed verifying the accuracy of the E point and incisural notch on the apexcardiogram as time markers for aortic valve opening and closure, respectively. The studies were carried out in 12 infants with congenital cardiac malformations undergoing cardiac catheterization, and in five infants with normal cardiovascular function in whom aortograms were performed for noncardiac causes. In each subject, an apexcardiogram, an aortic root pressure, a phonocardiogram, and an electrocardiographic lead were simultaneously recorded. Aortic pressures were recorded with a high-fidelity micromanometer-tipped catheter. Figure 2 represents a typical tracing. The E point of the apexcardiogram is sharply depicted and coincides in time with the beginning of the aortic upstroke. Similarly, the incisural notch of the apexcardiogram show precise time correspondence.

After confirming the accuracy of the apexcardiogram as a time marker for the points of aortic valve opening and closure, 150 clinically normal infants were studied. Of the group, 110 were newborns, 85 were full term, ranging from 2 hours to 5 days of age, and 25 were premature, ranging in weight from 610 to 2,100 g. The ages of the premature infants at the time of study ranged between 5 hours and 4 weeks. Forty infants, ranging in age from 1 month to 11 months, accounted for the remainder of the control study group. The sex

![Figure 1](image1.png)

**Figure 1**
A schematic of the simultaneously recorded central aortic pressure (Ao), apexcardiogram (ACG), electrocardiogram (ECG), and phonocardiogram (PCG). E = E point; DN = dicrotic notch; S1 = first heart sound; A2, P2 = aortic and pulmonic components of the second heart sound.

![Figure 2](image2.png)

**Figure 2**
Simultaneously recorded apexcardiogram and central aortic pressure in a patient with a patent ductus arteriosus. Time lines are 40 msec apart. Dashed lines at E and DN are drawn in. Central aortic pressure obtained with a high-fidelity micromanometer-tipped catheter. Phonocardiogram shows continuous murmur.

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distribution was nearly equal; 71 were male and 79 female.

Regression equations relating heart rate to systolic time intervals, standard errors, and coefficients of determination were calculated using a programmed IBM computer. The coefficients of determination of the ejection time and electromechanical systole were both > 0.70. Evaluation of the control data indicated that no statistically significant difference existed between the premature, full term, and older infants.

The control data confirmed the well known relationship of heart rate to ejection time. At heart rates ranging from 110 to 180 beats/min there was a distinct inverse linear relationship to both ejection time and electromechanical systole. The pre-ejection period did not seem to show a clear linear relationship to heart rate contrary to previous reports in the literature.\textsuperscript{1, 6}

The group of abnormal subjects consisted of 30 infants with congenital or acquired heart disease with clinical evidence of congestive heart failure. In 16 infants there was a large intracardiac left-to-right shunt at the atrial or ventricular level which was associated with the heart failure state. Three patients were studied with large patent ductus arteriosus, four with total anomalous pulmonary venous return, two with coarctation of the aorta, and five with one of the primary myocardial diseases.

\section*{Results}

\subsection*{Ventricular Septal Defects}

In the 11 patients with ventricular septal defect, the calculated pulmonary-to-systemic flow ratios ranged from 2.3-1 to 4.2-1 (mean 2.8-1). All were judged by clinical criteria to be in congestive heart failure at the time of the initial study. Eight were studied both before and after the administration of digitalis. In the acute untreated state, the ejection time and electromechanical systole were prolonged in each instance. Among the group of 11, six infants were restudied between 5 days and 2 months after initiation of decongestive therapy. In four, the ejection time and the time of electromechanical systole appeared to normalize. The values for ejection time and electromechanical systole relative to heart rate, initially abnormal, moved to within 2 SD of normal. Examples of this are shown in figure 3 (patients 7 and 11). Two patients, nos. 6 and 8 in figure 3, failed to show improvement clinically, which was reflected in a persistently prolonged ejection time. Patient 8, whose condition was

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{Relationship of electromechanical systole (EMS), ejection time (ET), and preejection period (PEP) to heart rate. The normal regression lines for EMS, ET, and PEP run diagonally across the illustration. The shaded areas on either side of each regression line represent 2\,\text{SD} of the norm. Open circles = values prior to digitalisation; solid circles = values after digitalisation; dotted lines = clinical course of patient 6; solid lines = pt 7; dot and dashed lines = pt 8; dashed lines = pt 11.}
\end{figure}
complicated by a cleft lip and palate, died of a massive aspiration pneumonia shortly after follow-up study. Patient number 6, because of intractable heart failure, required pulmonary artery banding. Three days after operation, the ejection time and the time of electromechanical systole were no longer prolonged, and instead appeared unexpectedly short.

**Interatrial Shunt**

There were five infants with a large left-to-right shunt at the atrial level and associated heart failure. Three of the five infants were affected with mongolism and the cardiac lesion consisted of an ostium primum defect. None of the three demonstrated significant mitral regurgitation on left ventricular angiocardiography, although one showed a small left ventricular-to-right atrial shunt. One patient with Holt-Oram syndrome had a small ventricular septal defect as an associated lesion. The pre-ejection period and the ejection time in each patient in this group of five fell within 2σ of the norm.

**Patent Ductus Arteriosus**

Three infants with isolated patent ductus arteriosus and congestive heart failure were studied. Two of the three were documented to have a patent ductus arteriosus as part of the postrubella syndrome. Each of the three failed to show a favorable response to medical management, which necessitated surgical intervention at 15 days, 30 days, and 2 months of age, respectively. One patient (fig. 4) showed progressive diminution of the ejection time relative to heart rate from the nineteenth day to the thirtieth day of age. Eight days after operation, when the patient no longer showed clinical signs of heart failure, the ejection time assumed a normal value. The pre-ejection periods were all within the lower range of normal during the period of heart failure and lengthened slightly on the eighth

![Figure 4](image-url)
postoperative day. Similar findings were noted in two other patients.

**Total Anomalous Pulmonary Venous Return**

Four infants with the nonobstructive variety of total anomalous pulmonary venous return were in congestive heart failure when studied and in each instance the ejection time and the preejection period fell within 2 SD of the norm.

**Primary Myocardial Disease**

A 12-month-old infant (patient 1 in fig. 5) was studied during the acute phase of viral myocarditis. The systolic time intervals were obtained before and after treatment with digitalis and other decongestive medications. Therapy produced dramatic clinical improvement in 48 hours. In this infant, only minor changes were noted in the systolic time intervals. A second infant, by contrast, (patient 2, fig. 5) with serologically proven coxsakie-B myocarditis was studied during the chronic phase of myocarditis and in this patient the preejection period was significantly prolonged while the ejection time was at the upper limits of normal for heart rate. A third patient (patient 3), a 2-month-old infant with chronic congestive failure due to endocardial fibroelastosis had similar findings to those noted in the patient with chronic viral myocarditis. The fourth patient (patient 4), a 2-month-old infant with aberrant origin of the left coronary artery from the pulmonary artery was first seen in the early acute stage of his illness at which time the study revealed normal preejection periods with a shortened ejection time. By contrast, patient 5 in figure 6, with the same cardiac malformation was studied during a chronic phase of congestive heart failure and he showed a prolonged preejection period and a normal ejection time. Further prolongation of the preejection period was noted 1 month following the initial study. One month following ligation of the anomalous left coronary

**Figure 5**

*In patient 1, indicated by dashed line, with acute viral myocarditis, systolic time intervals were obtained before and after digitalis therapy at heart rates of 141 and 110 beats/min respectively. In patient 2, with chronic viral myocarditis, systolic time intervals were recorded only at a heart rate of 118. Patient 3, with endocardial fibroelastosis, systolic time intervals were measured at rates of 138 and 111. Patient 4, with anomalous left coronary artery arising from the pulmonary artery, systolic time interval values were recorded at a heart rate of 145. Patient 5, with anomalous left coronary artery arising from the pulmonary artery, systolic time interval values were obtained at heart rates of 162 and 150. See text for discussion.*

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artery at its juncture with the pulmonary artery, the systolic time intervals failed to show a significant change.

Discussion

A variety of instruments are available for the purpose of studying low-frequency precordial or arterial pulsations.4, 5, 7, 8, 9, 11, 14, 15 In clinical laboratories, the device most frequently used is the funnel pick-up which is coupled by air-filled tubing to either an air-filled pressure transducer or a linear crystal microphone. Whereas this type of instrumentation seems generally suitable to the adult, its application to the infant, in our experience, has been consistently unrewarding. Graphs of low-frequency pulsations obtained from infants are characteristically damped and display indiscernible end points which make accurate timing of the cardiac events virtually impossible.

When a contact crystal microphone, however, was interfaced directly to the chest wall over the point of maximum cardiac impulse, graphs were recorded with sharp end points marking at least two distinct events in the cardiac cycle. The point of ejection (E point) and the incisural notch were easily identified on the apexcardiogram despite, at times, marked undulations in the graph due to respiratory movements. The placement of the microphone foot plate 1–2 cm lateral to the lower left sternal border in some cases, seemingly over the right ventricle, generally yielded the best results. Recording of left ventricular events from this site was verified by repeated checks with high-fidelity micromanometer-tipped catheters during cardiac or aortic catheterization in infants with and without intracardiac disease. In the way of further confirmation, we have shown in the animal laboratory that left ventricular events are clearly discernable in graphs of low-frequency pulsations obtained by the gentle application of a contact crystal microphone to the exposed right ventricle of a beating canine heart (Steinfeld L, Dimich I, Park SC: Unpublished data).

Analysis of the data derived from this investigation highlighted the fact that there is no one systolic time interval or pattern of systolic time intervals which is pathognomonic of the heart failure state in the infant. The infant in heart failure as a consequence of a large isolated ventricular septal defect consistently shows prolongation of the ejection time and a normal pre-ejection period. Total electromechanical systole was prolonged in each instance. These findings differ with observations reported in the adult with arteriosclerotic or hypertensive disease and heart failure6 in whom there is prolongation of the pre-ejection period, a shortening of the ejection time, and a fairly constant period of total electromechanical systole. The prolonged pre-ejection period in the adult in heart failure probably reflects the intrinsic defect in myocardial contractility fundamental to the heart failure state. In the infant with a large ventricular septal defect and heart failure, the presence of a normal pre-ejection period would suggest that the myocardial factor is perhaps of lesser importance in the genesis of heart failure. The prolonged ejection time in these infants is undoubtedly a function of volume overload, but myocardial failure alone may account for a part of the prolongation by a mechanism as yet unexplained. It is interesting to note that when cardiac compensation is restored and forward cardiac output improved, either medically with an appropriate cardiotonic regimen or surgically by banding the pulmonary artery, the previously prolonged ejection time shortens whereas the pre-ejection period does not show a significant change.

Studies performed in two infants with secundum atrial septal defect, three with ostium primum defects, and four with total anomalous pulmonary venous drainage all registered normal left ventricular systolic time intervals. Values in this sampling were not significantly different during the acute episode of heart failure compared to values obtained when treatment succeeded in improving cardiac performance. These findings are predictable in light of the fact that the left ventricle is not burdened by predominantly left-to-right shunts occurring at the atrial level.

The systolic time intervals in the infants with patent ductus arteriosus were unique in that the pre-ejection periods were characteristically shorter than normal while the ejection times were either short or within the normal range. Reduced systemic vascular resistance and rapid aortic runoff characteristic of high-flow patent ductus arteriosus account in large measure for the more rapid ejection time while the shortened pre-ejection period, as noted by Shaver et al.16 and others,17 is predominantly a function of a reduced aortic end-diastolic pressure with earlier aortic valve opening and a shorter time span between the initiation of electrical systole and the onset of aortic ejection.

In contrast to the findings in patent ductus arteriosus and other varieties of congenital heart disease, infants with myocarditis or subendocardial...
fibroelastosis and associated chronic heart failure tend to show a prolonged preejection period. The preejection period encountered in the chronic heart failure of myocarditis or endocardial fibroelastosis seems to parallel observations of the preejection period in adults with arteriosclerotic or hypertensive heart disease and chronic heart failure.\(^5\)\(^-\)\(^7\) Systolic time intervals may be normal during the acute phase of heart failure due to viral myocarditis, as observed in one case of proven coxsackie-B myocarditis. In the case of aberrant origin of the left coronary from the pulmonary artery complicated by a recent acute anterolateral myocardial infarction and heart failure, the preejection period was consistently found to be normal while the ejection time was shortened. Identical findings have been reported in adults with acute myocardial infarction and diminished left ventricular output.\(^1\)\(^8\) Aberrant origin of the left coronary artery from the pulmonary artery studied at a later stage when chronic heart failure dominates the clinical picture, showed prolongation of the preejection period. Heikkila et al.\(^1\)\(^9\) and Hodges and co-workers\(^2\)\(^0\) observed a parallel situation in the adult with acute myocardial infarction. Left ventricular ejection times were at first shortened, but by 20 days-4 weeks the left ventricular ejection times tended to normalize. Others have reported prolongation of the preejection period in myocardial infarction with chronic congestive heart failure.\(^1\)\(^8\), \(^2\)\(^1\)

In summary, our preliminary observations on systolic time intervals in infants with heart failure indicate that there is no single interval or pattern of intervals that distinctly signal the presence of heart failure. The systolic time intervals associated with heart failure in a specific disease entity appear to be consistent. However, modification of systolic time interval values may occur as a result of treatment intervention, chronicity of disease, and a variety of other factors that alter the hemodynamic state. In the majority of cases of heart failure in congenital heart disease the preejection periods tend to fall within the normal range of values which is contrary to observations reported in the arteriosclerotic or hypertensive adult. The data in the congenital heart disease patients suggest that the impairment of myocardial contractility may not be so important a factor in the production of the heart failure state as it seems to be in acquired myocardial disease. Although the current investigation is preliminary and limited in scope, there is the impression that with further refinement in technic and accumula-

References


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