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Computer analysis of cardiac contractility variables obtained by M-mode echocardiography in normal newborns

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SUMMARY There are few echocardiographic studies which examine ventricular cavity and wall dimensions as well as ventricular function in normal newborn infants. We investigated the M-mode echocardiograms of 60 normal newborn infants aged 3 to 6 days using computer analysis. Using the same method, we examined in addition left ventricular cavity dimensions and contractility variables of 15 healthy newborn infants sequentially during the first hour of life. The left and right ventricular diameters, their systolic shortening fraction and maximal rate of change, as well as the thickness of the interventricular septum and the left ventricular posterior wall were found to be comparable to previously published values. In addition, we found that the left ventricular end-diastolic diameter and the systolic shortening fraction of the left ventricular diameter increase significantly during the first hour of life. This increase is probably because of the postnatal increase in left ventricular volume and pressure work.

M-mode echocardiography is useful for studying normal and pathological cardiac anatomy in newborn infants. In addition, it provides information on the size and function of the left ventricle and, within limits, the right ventricle. In order to obtain normal values in newborns, we analysed the M-mode echocardiograms of 60 newborn infants without heart disease by computer, as first described by Gibson and Brown.[1]

During fetal life, both cardiac ventricles function in parallel, the right ventricle pumping about two thirds and the left ventricle about one third of the combined cardiac output. After birth, both ventricles function in series; while the right ventricular output remains unchanged, the left ventricular output increases by about one third of its prenatal volume.[2-4] In order to investigate the adaptation of the left ventricle to this higher volume load immediately after birth, we examined in addition left ventricular cavity dimensions and contractility variables in 15 healthy newborns sequentially during the first hour of postnatal life.

Methods

M-mode echocardiograms were obtained in 60 newborns without heart disease according to a method described by Solinger *et al.*[5] Twenty nine of the newborns were female and 31 were male, their ages ranging from 3 to 7 days. The mean body weight was 3206 g, the mean body length 49·4 cm. An unfocused 5 MHz transducer with an active crystal diameter of 6 mm was used. The echocardiograms were obtained in the usual manner while the newborns were lying supine or in slight left decubitus position. Recordings were made at a paper speed of 100 mm per second.

Echoes of the right and left ventricular cavity and of the interventricular septum were obtained at the level of the mitral valve. The echoes of three to four consecutive cardiac cycles were digitised using an x-y tablet with cursor and processed by computer* using a program especially developed for this purpose. For time reference the beginning of the corresponding QRS complexes of the electrocardiogram was digitised. The computer provided plots of continuous right and left ventricular cavity dimensions as well as septal and left ventricular wall thickness.

The following variables were measured or calculated, respectively: the end-diastolic diameter (D_o) of the right and left ventricle at the beginning of the QRS complex, the shortest end-systolic diameter (D_{min}) of the right and left ventricle, the percentage

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change of ventricular diameter in systole (SF) calculated according to the formula

$$SF = \frac{D_o - D_{min}}{D_o} \times 100\,(\%),$$

and the normalised velocity of change of ventricular dimension VCF calculated according to the formula $V_{CF} = \frac{1}{D} \times \frac{dD}{dt}$ per second (Fig. 1) (this latter variable is independent of ventricular size and thus allows comparison between ventricles of different sizes). The results are expressed as the maximal shortening velocity of the left and right ventricular diameter during systole (VCF_{min}) and the maximal velocity of lengthening of the left and right ventricular diameter during diastole (VCF_{max}). The thickness of the interventricular septum ($D_{o\ ivs}$) and the left ventricular posterior wall ($D_{o\ pw}$) at the beginning of the QRS complex, the maximal thickness of the interventricular septum ($D_{max\ ivs}$) and of the left ventricular posterior wall ($D_{max\ pw}$), and the percentage of systolic thickening (ΔD (%)) of the interventricular septum and posterior left ventricular wall were also measured or calculated, respectively. The mean values of three to four consecutive cardiac cycles were taken as representative. The heart rate was calculated from the simultaneously recorded electrocardiogram.

Measurements and calculations were done only if the echoes were clearly identifiable and could be analysed continuously throughout the cardiac cycles. The left ventricular diameter and derived variables were obtained in all 60 newborns. The left ventricular posterior wall could be analysed in 56, the interventricular septum in 43, and the right ventricle in 23 newborns.

In addition, 15 newborns were studied several times during the first hour of life after normal delivery. Left ventricular echocardiograms were obtained in consecutive intervals of 10 minutes, beginning at 10 minutes and ending 60 minutes after birth. The echocardiograms were recorded and analysed as described above.

For statistical analysis a one factor randomised block design for the variables D_o, D_{min}, SF, VCF_{min}, and VCF_{max} was done.[6] The global significance level was

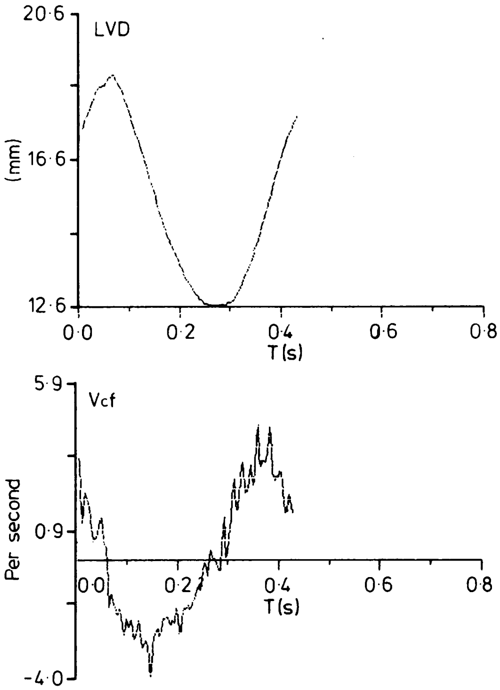

Fig. 1 *Upper panel: left ventricular diameter (LVD) during one cardiac cycle. Lower panel: unsmoothed curve of normalised velocity of change of left ventricular diameter (VCF) during the same cardiac cycle as shown in the upper panel.*

assumed to be 5%. For testing the time differences a simultaneous test procedure as described by Gabriel was done. For the variable SF a trend analysis was performed.[7]

Results

The results for both ventricles are summarised in Table 1, and those for the interventricular septum and left ventricular posterior wall in Table 2.

The left ventricle has an end-diastolic diameter of 15·7±2·1 mm (mean±SD) and a systolic diameter of 10·3±2·1 mm. The percentage change of left ventricular diameter in systole is 34·3±8·2%. The maximal velocity of shortening (VCF_{min}) and lengthening

Table 1 *M-mode echocardiographic variables of right and left ventricle in 60 newborns 3 to 7 days of age*

	$D_o \pm SD$ (mm)	$D_{min} \pm SD$ (mm)	$SF \pm SD$ (%)	VCF_{min}/s (±SD)	VCF_{max}/s (±SD)
Right ventricle n=23	10·0±1·8	7·7±1·6	22·4±9·6	−4·07±2·25	4·3±2·09
Left ventricle n=60	15·7±2·1	10·3±2·1	34·4±8·2	−4·64±1·49	6·28±3·13

Table 2 *M-mode echocardiographic variables of interventricular septum and left ventricular posterior wall in 60 newborns 3 to 7 days of age*

	D_o±SD (mm)	D_{max}±SD (mm)	ΔD±SD (%)
Interventricular septum n=43	4·5±1·3	6·1±1·4	39·8±17·2
Left ventricular posterior wall n=56	3·1±0·7	5·2±0·9	73·8±44·6

(VCF_{max}) of the left ventricular diameter is 4·64±1·49 and 6·28±3·13 per second, respectively. The end-diastolic diameter of the right ventricle measures 10·0±1·8 mm, the end-systolic diameter 7·7±1·6 mm. The percentage change of right ventricular diameter is 22·4±9·6 (%). VCF_{min} and VCF_{max} of the right ventricle are 4·07±2·25 and 4·3±2·09 per second, respectively. The interventricular septum has a mean end-diastolic thickness of 4·5±1·3 mm and a maximal systolic thickness of 6·1±1·35 mm. The percentage systolic increase in thickness of the interventricular septum amounts to 39·8±17·2%.

End-diastolic and maximal systolic thickness of the left ventricular posterior wall are 3·1±0·7 mm and 5·2±0·85 mm, respectively. The percentage systolic increase in posterior wall thickness is 73·8±44·6%.

Large variance prevented us from calculating the velocity of change in thickness of the interventricular septum and left ventricular posterior wall.

The results of the study of 15 normal newborns during the first hour of life are shown in Table 3. During the first hour of life the left ventricular end-diastolic diameter (D_o) increased significantly from 15·5±3·2 mm 10 minutes after birth to 17·1±3·1 mm 60 minutes after birth ($p<0·01$); in contrast, the end-systolic diameter remained unchanged at 11·0±2·7 and 11·1±2·4 mm, respectively. Accordingly, the percentage change of left ventricular diameter in systole (SF) increased from 29·2±7·4% 10 minutes after birth to 35·6±5·2% 60 minutes after birth ($p<0·005$) in a linear fashion. VCF_{min} showed a slight but not significant increase from 4·29±1·2 per second 10 minutes after birth to 4·93±1·0 per second 60 minutes after birth ($0·1>p>0·05$) (Fig. 2). VCF_{max} increased but not significantly from 5·6±2·1 at 10 minutes to 6·4±2·0 per second 60 minutes after birth. The heart rate remained stable at 161±13 and 158±15 beats per minute, respectively.

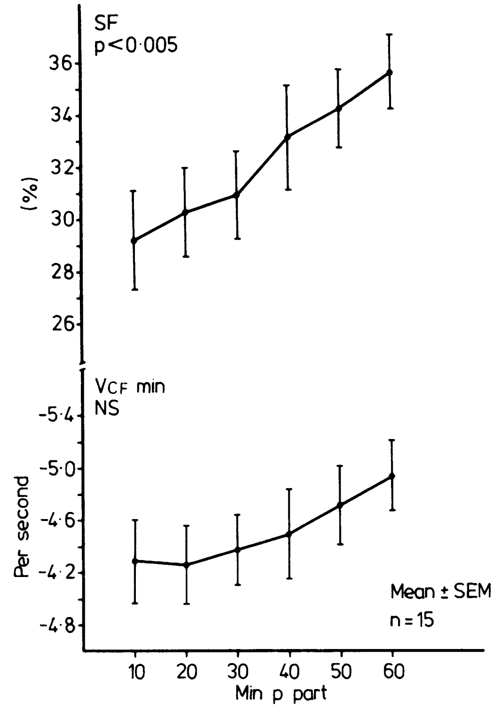

Fig. 2 *Percentage change of left ventricular diameter in systole (SF) (upper panel) and maximal shortening velocity of the left ventricular diameter during systole (VCF_{min}) (lower panel) during the first hour of life in 15 normal newborns. The difference between the values at 10 and 60 minutes of life for SF is statistically significant ($p<0·005$) while for VCF_{min} it is not significant ($0·1>p>0·05$).*

Discussion

There are few echocardiographic studies systematically examining ventricular function and dynamics in normal newborn infants. Sahn *et al.*[8] found a significant increase in mean VCF, a variable comparable to SF, during the first hour of life in seven newborn

Table 3 *M-mode echocardiographic variables of left ventricle in 15 newborns 10, 20, 30, 40, 50, and 60 minutes of age*

Minutes after birth	D_o *(mm)*	*D min (mm)*	*SF (%)*	VCF_{min}/s	VCF_{max}/s	*HR/min*
10	15·5±3·2	11·0±2·7	29·2±7·4	4·3±1·2	5·6±2·1	161±13
20	16·6±2·4	11·7±2·1	30·3±6·6	4·3±1·2	5·6±2·3	155±11
30	16·9±2·6	11·7±2·5	30·9±6·6	4·4±1·0	5·6±1·9	160±13
40	17·3±2·5	11·8±2·6	33·1±7·7	4·4±1·3	5·5±2·4	155±10
50	16·7±3·0	11·1±2·5	34·2±5·8	4·7±1·1	6·1±3·1	155±14
60	17·1±3·1	11·1±2·4	35·6±5·2	4·9±1·0	6·4±2·0	158±15

infants after caesarian section. St John Sutton *et al.*[9] investigated cardiac function in the normal newborn using computer analysis; the results of the variables studied both in their work and in this study are comparable. Lange *et al.*,[10] comparing left and right ventricular diameters before and after birth, found a decrease in the right ventricular diameter after birth while the left ventricular diameter remained unchanged.

Comparing the data of normal newborns with those from three to seven days after birth, we found that the left ventricular end-diastolic diameter increased from 10 minutes to 60 minutes after birth but, at the age of 3 to 7 days, it equalled the former value. The percentage change of left ventricular diameter in systole (SF) also increased from 10 minutes to 60 minutes after birth but was found unchanged at 3 to 7 days after birth.

The change during the first hour of life may be the result of the postnatal increase in left ventricular volume work. During fetal life right and left ventricles function in parallel. In the fetal lamb the left ventricle pumps 150 ml/kg per min and the right ventricle 200 ml/kg per min, respectively. After birth, both ventricles pump in series 200 ml/kg per min. This implies an increase in left ventricular output of 33%.[4] At the same time, the left ventricular systolic pressure increases from 60 mmHg before to 75 mmHg after birth. This increase in systolic pressure is most probably the result of closure of the low resistance placental circulation.[3] Gessner *et al.*[11] studied the left and right ventricular output in the first two hours of life using the indicator dilution technique. They found a higher left than right ventricular output caused by ductal left to right shunt at this age. Emmanouilides *et al.*[12] also found a left to right ductal shunt with higher left than right ventricular outputs in the first hours of life. Thirteen to 15 hours postnatally they found the ductus arteriosus functionally closed in all newborns.[12]

The fact that the left ventricular end-diastolic diameter (D_o) increases in the first hour of life, but that at the age of 3 to 7 days it is equal to the value at 10 minutes of age may reflect adaptation of the left ventricle to increased work using the Frank-Starling mechanism.

We conclude that left ventricular contractility in normal newborns increases during the first hour of life and, at 1 hour of life, it is identical to that of older newborns, infants, and children.[13 14]

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