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Changes in Hemodynamics during the Neonatal Period *

An Echocardiographic Study

(hemodynamics/neonates/echocardiography)

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We performed echocardiography on neonates sequentially and investigated the changes in hemodynamics during the neonatal period. Twenty newborn infants (male : ten, female : ten, gestational age : 34–41 weeks, birth weight : 1540–4100 g) were examined. The first examination was performed within one day after birth, and the second examination two to six days thereafter. Six indices of hemodynamics were analyzed on both sides of the heart ; the ratio of pre-ejection period to the ejection time (LPEP/LVET, RPEP/RVET), end diastolic ventricular dimension (LVDd, RVDd), and shortening fraction of ventricular dimension (SFLVD, SFRVD).

Gestational age or heart rate did not affect these indices, while birth weight closely correlated with LVDd and RVDd ($r=0.44$ and 0.66, respectively). The mean±standard deviation of the indices at the first and the second examinations were : cardiac cycle : 0.48±0.06 sec and 0.47±0.08 sec, LPEP/LVET : 0.34±0.07 and 0.28±0.06, RPEP/RVET : 0.41±0.11 and 0.27 ±0.06, LVDd : 1.76 ±0.20 cm and 1.79±0.21 cm, RVDd : 1.50 ± 0.20 cm and 1.61±0.22 cm, SFLVD : 0.32±0.06 and 0.35± 0.06, SFRVD : 0.26 ± 0.08 and 0.29±0.07.

In the series of examinations, LPEP/LVET and RPEP/RVET decreased and LVDd and RVDd increased, suggesting that the reduction in the afterload on both ventricles, the improvement of left ventricular contractility, and the increase in the preload of the ventricles may take place during the first week after birth.

Abbreviations
LPEP : left pre-ejection period RPEP : right pre-ejection period LVET : left ventricular ejection time RVET : right ventricular ejection time LVDd : left ventricular dimension at end diastole RVDd : right ventricular dimension at end diastole LVDs : left ventricular dimension at end systole RVDs : right ventricular dimension at end systole SFLVD : shortening fraction of left ventricular dimension SFRVD : shortening fraction of right ventricular dimension STIs : systolic time intervals

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A variety of events take place following birth. Among these events, the change in the cardiovascular system, that is, the switch from fetal to extra-uterine circulation is the most dramatic. The abnormality of this process may bring about various problems in infant life. Further, some diseases such as pulmonary hypertension, patent ductus arteriosus, etc., are in close relation to the shift in the cardiovascular system (1). Knowledge concerning the circulatory state in the neonatal period is, therefore not only essential to clarify cardiovascular physiology in early infancy but also to understand normal and pathological states of circulation in later life.

We examined newborn infants sequentially using noninvasive methods, mainly echocardiography, and studied the change in hemodynamics during the neonatal period.

MATERIALS AND METHODS

Twenty newborn infants were examined. The consent concerning the examination was received from the family of each infant. Physical and laboratory examinations including echocardiography itself revealed that there were no cardiopulmonary abnormalities. Sex, gestational age, birth weight and the age at the examinations are listed on Table I. Gestational age ranged from 34 to 41 weeks and birth weight from 1450 to 4100 g. Three neonates (numbers 10, 11, 20) were large for date, one (number 5) was small for date, and the others were appropriate for date.

TABLE I. *Subjects*

# Infant	Sex	Gestational age (wk)	Birth weight (gm)	1st exam. (hr)	2nd exam. (hr)
1	F	34	2200	6	150
2	F	34	2400	6	150
3	F	35	2060	4	76
4	F	35	2450	4	76
5	M	37	1540	6	124
6	M	37	2620	6	52
7	M	37	3400	10	101
8	F	38	3520	9	54
9	M	38	3600	11	80
10	M	38	3640	15	84
11	M	38	4000	8	56
12	F	39	3010	19	70
13	M	39	3060	4	59
14	M	39	3220	9	56
15	F	39	3420	11	59
16	M	40	3040	1	48
17	M	40	3440	8	53
18	F	40	3680	12	130
19	F	41	2980	11	58
20	F	41	4100	9	100

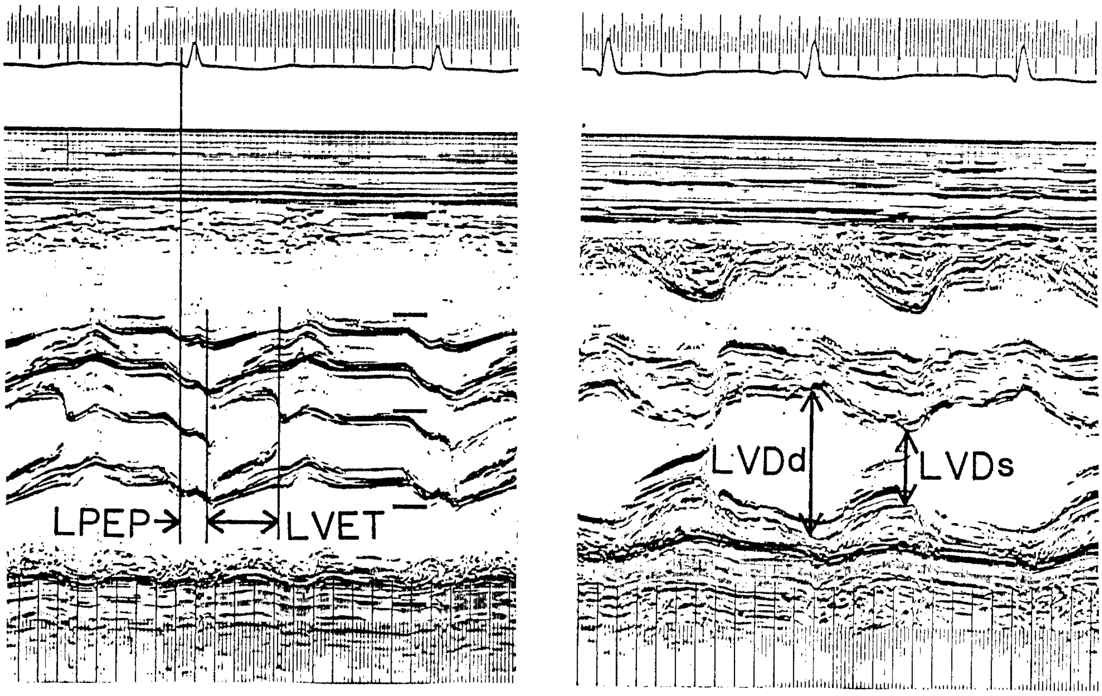

Fig. 1. Left, aortic valve echogram. LPEP is measured as the interval from the onset of QRS complex of electrocardiogram to the echogram of aortic valve opening. LVET is measured from the opening to the closure echogranm of the aortic valve. Right, left ventricular echogram. LVDd is measured as the dimension between the endocardial echo of the interventricular septum and that of the left ventricular posterior wall at the QRS complex of the electrocardiogram. LVDs is the same dimension at the peak anterior motion of the posterior wall.

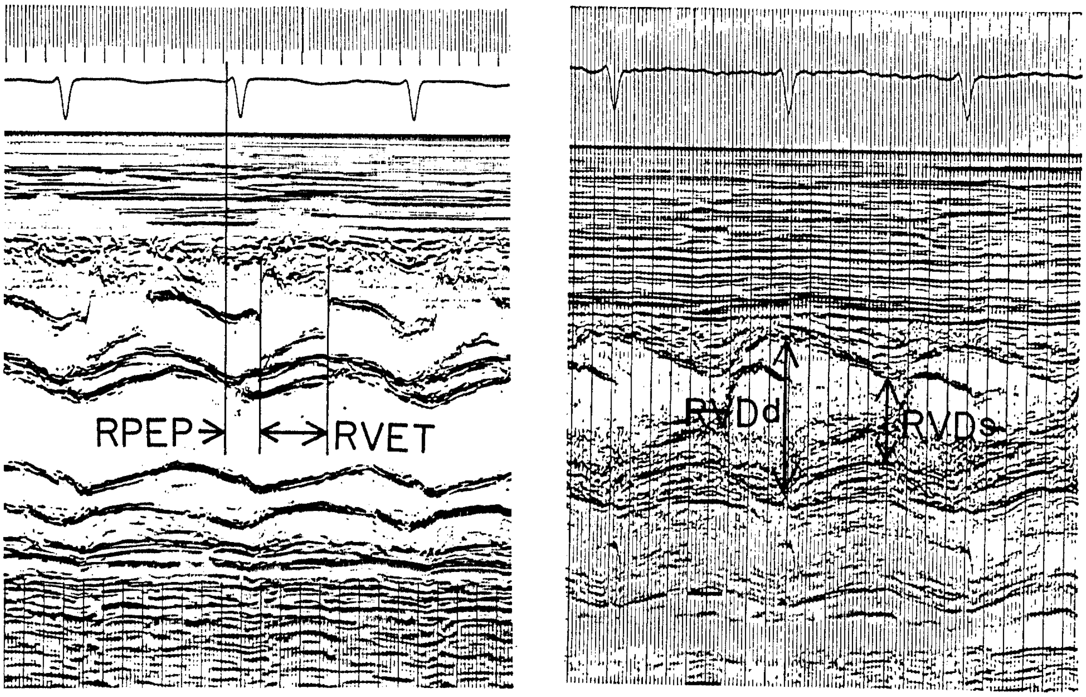

Fig. 2. Left, pulmonary valve echogram. RPEP is measured as the interval from the onset of the QRS complex to the echogram of the pulmonary valve opening. RVET is measured from the opening to the closure echogram of the pulmonary valve. Left, right ventricular echogram. RVDd is measured as the dimension between the endocardial echo of the anterior right ventricular wall and the echo of the anterior aortic wall at the QRS complex. RVDs is the same dimension at the peak anterior motion of the anterior wall of the aorta.

Echocardiography and electrocardiography were performed simultaneously, employing Aloka 110S or Electronics for Medicine VR-12 echo-polygraph, and 3.5 or 5 MHz transducer. These were recorded on a strip chart at the speed of 100 mm/sec. The infants were examined while they were unsedated, breathing naturally, and in a supine position. As shown on Table I, the examinations were carried out twice on each infant ; first within one day after birth, and the second between two to six days thereafter.

The M-mode echograms of aortic and pulmonary valves, left and right-ventricles were obtained ; the echogram of the right ventricle through the ultrasound emitted from the subxiphoid space and the others through that from the left parasternal area. An evaluation of right ventricular size and motion is extremely difficult. The subxiphoid approach is superior to the parasternal approach when attempting to estimate the size of the right ventricle (2, 3).

Figs.1 and 2 show the examples of echogram and the methods of measurement. We measured pre-ejection periods (LPEP, RPEP), ventricular ejection times (LVET, RVET), ventricular dimensions at end diastole (LVDd, RVDd) and those at end systole (LVDs, RVDs) according to the standard methods (3—5). Based on these measurements, three indices of hemodynamics at each side of the heart were calculated and analyzed, namely, the ratios of pre-ejection period to the ejection time (LPEP/LVET, RPEP/RVET), the shortening fractions of ventricular dimension (SFLVD, SFRVD), and the ventricular dimensions at end diastole themselves. The shortening fractions were calculated with the formulas :

$$SFLVD=(LVDd-LVDs)/LVDd=1-LVDs/LVDd$$

$$SFRVD=(RVDd-RVDs)/RVDd=1-RVDs/RVDd.$$

Differences between the value of indices at the first and the second examinations were assessed by paired t-test.

RESULTS

The infants were breathing naturally, so some heart beats were at inspiration and others at expiration. The fluctuation of the measurement from beat to beat is in part due to the respiration. The fluctuation in the value of

TABLE II. *Correlation Coefficient of the Indices with Related Factors*

Index	R-R interval	Gestational age	Birth weight
LPEP/LVET	−0.17	−0.26	−0.10
LVDd	0.09	0.60	0.66
SFLVD	0.00	0.03	0.06
RPEP/RVET	−0.17	−0.10	−0.20
RVDd	0.36	0.11	0.44
SFRVD	−0.29	0.03	0.00

each measurement was, however, minimal and even if present might be rounded because measurements on several beats were averaged.

The gestational age and the birth weight of our infants were variable. Their heart rate changed not only from baby to baby but also from examination to examination. Table II shows the relation of each index to the R-R interval of simultaneous electrocardiography, namely cardiac cycle, gestational age, and birth weight, at the first examination. Among the indices analyzed,

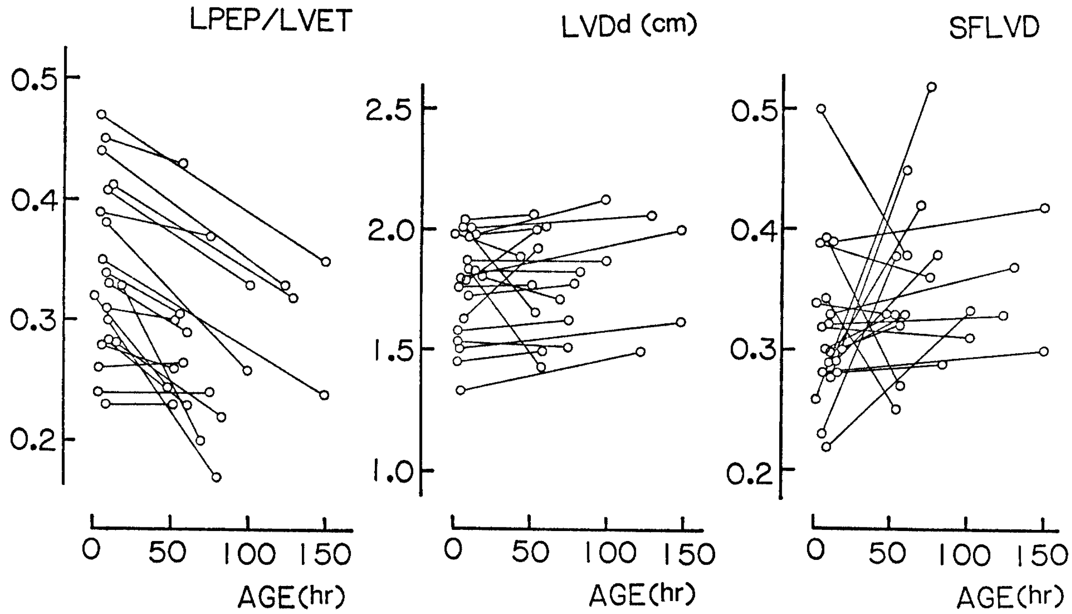

Fig. 3. Age-dependent change of LPEP/LVET, LVDd and SFLVD. LPEP/LVET decreases in almost all cases. LVDd increases in many cases. No constant trend of change is apparent as for SFLVD.

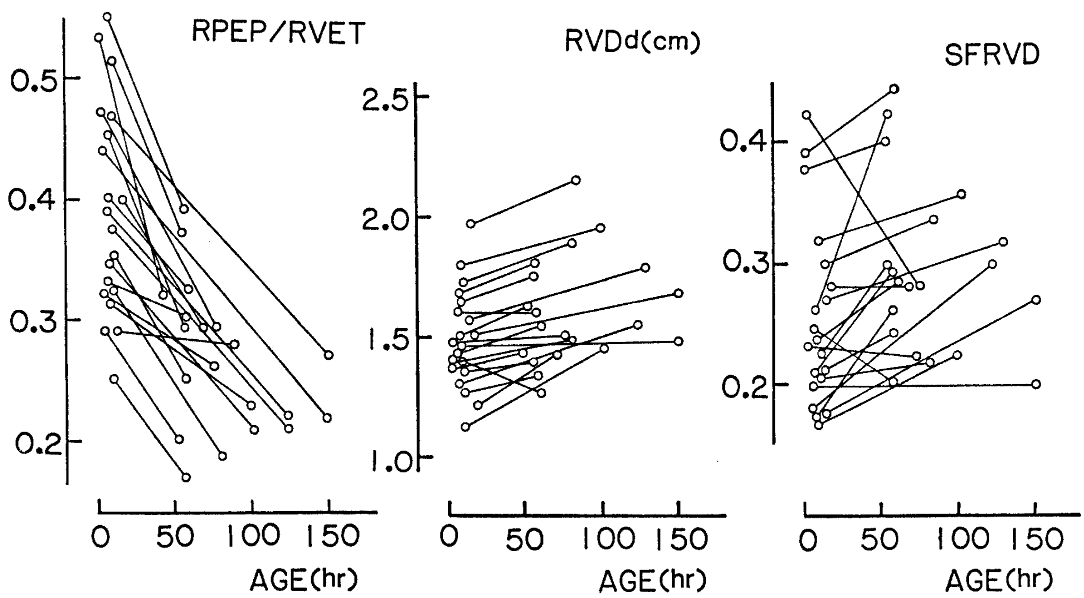

Fig. 4. Age-dependent change of RPRP/RVET, RVDd and SFRVD. RPEP/RVET decreases, in all cases. RVDd increases in almost all cases. No constant trend of change is apparent as for SFRVD, though in some cases it may increase.

ventricular dimensions (LVDd and RVDd) positively correlated with birth weight, suggesting that ventricular size increases as the baby grows. Heart rate and gestational age did not seem to affect any index.

Figs. 3 and 4 show the changes of the six indices in relation to the age. At the second examinations, the ratios of pre-ediction period to the ejection time decreased in most cases, and the ventricular dimensions increased in a considerable number of cases, although the amount of the increment was very small. In contrast to those four indices, no constant change with age was apparent in the shortening fractions of the ventricular dimension, some of which increased while others decreased. The mean and the standard deviation of each index at the first and the second examination is listed in Table III. The decrease in LPEP/LVET and RPEP, and the increase in RVDd were significant.

TABLE III. *Value of Indices at the First and the Second Examinations*

Index	1st exam.		2nd exam.		Significance
	mean	s. d.	mean	s. d.	
LPEP/LVET	0.34	0.07	0.28	0.06	$p<0.01$
LVDd (cm)	1.76	0.20	1.79	0.21	n. s.
SFLVD	0.32	0.06	0.35	0.06	n. s.
RPEP/RVET	0.41	0.11	0.27	0.06	$p<0.01$
RVDd (cm)	1.50	0.20	1.61	0.22	$p<0.01$
SFRVD	0.26	0.08	0.29	0.07	n. s.

DISCUSSION

A "switching" occurs in the cardiovascular system just after birth. The principal events included are, 1. cessation of placental blood flow, 2. closure of foramen ovale and ductus arteriosus, and 3. decrease in pulmonary vascular resistance. These events bring about various changes in the functional state of the heart. In the extrauterine circulation, left and right ventricles work separately to extrude all the circulating blood, while in the fetal circulation they work concomitantly with one another and the pulmonary blood flow is only ten percent of the systemic flow (1) (Fig. 5). As a result, an increase in the preload on both ventricles may take place. Cessation of placental blood flow and decrease in pulmonary vascular resistance may result in a decrease in the afterload on the ventricles. Exposure to the air, respiratory effort, and other factors may affect the oxygen demand, humoral or neurological circumstances of the heart, so that the ventricular contractility may be affected.

The estimation of cardiac function with the aid of echocardiography is now well established. Though some theoretical or technical problems remain to be investigated, this method allows for acquisition of cardiovascular events, successively and with minimal invasion.

We analyzed three indices of cardiac funcion on each side of the heart.

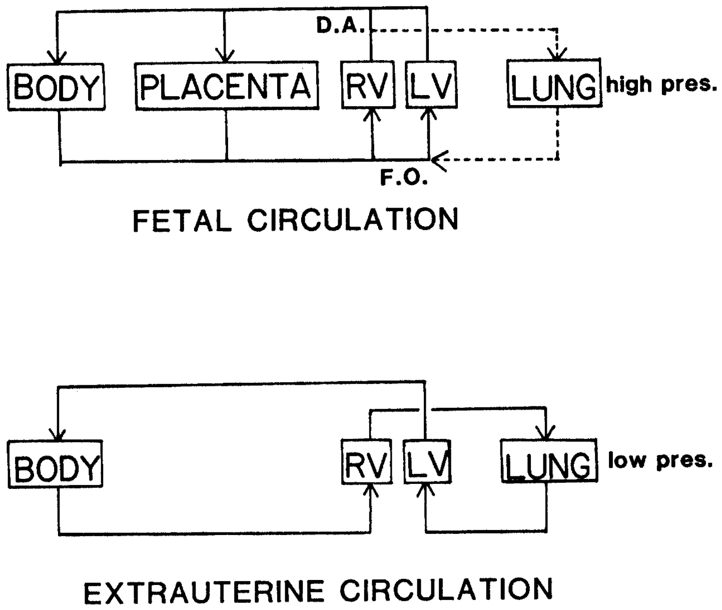

Fig. 5. Top, fetal circulation. Ductus arteriousus, foramen ovale and umbilical vessels are patent. Pulmonary flow is scanty. Left and right ventricles work concomitantly (in parallel). Bottom, extrauterine circulation. Ductus arteriousus and foramen ovale are closed. Placental flow has ceased. Pulmonary flow is equal to systemic flow, and left and right ventricles work separately to extrude all the circulating blood (in series).

The ratio of the pre-ejection period to the ejection time decreased remarkably during one week after birth, as was noted by other investigators (6, 7). Such reflects the afterload of the ventricle, while LPEP/LVET reflects the contractility of the left ventricle as well (7—9). Afterloads on both ventricles are apparently reduced during this period. Ventricular end diastolic dimension increased by a relatively small amount. Left and right ventricular end diastolic dimensions are regarded as indices of the preload on the corresponding ventricle, similarly to the end diastolic volumes which are calculated from the dimensions themselves (10—12). Thus, it is assumed that the preload on the ventricles increases, though the increase of the dimension may come with growth. The shortening fraction of the ventricular dimension is an index of ventricular contraction, analogously with the ejection fraction (13—15). In our infants, it did not alter significantly. Whether there is a lack of a trend in change in ventricular contraction is not apparent, because this index is, compared to others, more subject to changes in the condition of the patients.

The gestational age and birth weight of the newborn infants we examined differed; therefore, size and the functional state of the heart may also differ. In addition, it is difficult to maintain constant conditions when infants or children are sometimes crying and sometimes asleep. Depth of respiration and, above all, the heart rate cannot be made constant. Since the size of the whole body determines the size of the heart, birth weight was in close correlation with ventricular dimensions. On the other hand, the ratio of the pre-ejection period to the ejection time and the shortening fraction of the ventricular dimension, which are the indices of afterload and contraction, were not affected by gestational age, body size, heart rate or respiration, in our series of examinations. They are thus expected to be advantageous for application in adverse conditions in pediatric practice.

Finally, a variety of alterations in cardiac functions occurring in newborn infants can be determined noninvasively through echocardiography even though the gestational age, birth weight or physical conditions may differ at the time of the examination.

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