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Ultrasound examination of blood flow. I. Flow in the fetal aorta

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The descending part of the fetal aorta was examined in a total of 101 healthy pregnant women on 146 occasions between the 28th and 41st weeks of pregnancy. A Kranzbühler 8130 Duplex Doppler apparatus was used throughout. It was found that the blood flow compared to the estimated fetal weight was near to the same value (180–200 ml/min/kg) during the third trimester. The absolute volume of blood flow—not related to fetal body weight—increased about three times from the 28th week to term (200–600 ml/min). The diameter of the fetal aorta increased from 3–4 mm to 7–8 mm during the 3rd trimester. The velocity of blood flow fluctuated between wide limits (20–40 cm/sec), but the average was 28–32 cm/sec. The A/B ratios (A = systolic peak, B = end diastole), the Resistance Indexes $\left(\frac{A-B}{A}\right)$, the Pulsatility Indexes $\left(\frac{A-B}{\text{mean frequency}}\right)$ were nearly the same during the third trimester.

Examination of the fetal cardiac and circulatory system was for long equivalent to examine the fetal heart by stethoscope. Later, use of the cardiotocograph was adopted and the fetal heart and big vessels could be made visible by B-mode ultrasound. In 1977, a non-invasive method was described [5, 11] where the ultrasound B-mode was combined with Doppler technique and in this way it became possible to study the fetal blood flow velocity waveforms. Then Gill [6] described the quantitative examination of the fetal blood flow by this method, and in 1980 Eik-Nes et al [2] applied the procedure to study the blood flow in the fetal aorta.

The aim of the present work was to study the blood flow velocity waveforms of the fetal aorta and to measure the quantitative value of the blood in the third trimester of pregnancy. Furthermore, we intended to give some data of the fetal physiological circumstances by the help of measuring the diameter of the fetal aorta and the velocity of blood flow.

MATERIAL AND METHODS

A total of 101 healthy pregnant women were examined on 146 occasions between the 28th and 41st weeks of gestation. Their average age was 24.2 (from 17 to 41) years. They were free from complaints, they did not use drugs except haemopoetics and

none of them was a smoker. The date of the last menstrual period was exact in all cases, and the age of pregnancy was also supported in the first trimester by ultrasound examination in 80% of the cases. All examinations were performed by the same person (A.P.).

The principle of the examination was based on the Doppler effect, i.e. if a static source emits some sound that is reflecting from a moving surface, the frequency of the sound will change depending on the direction and the velocity of the moving object. If the direction of the moving object is near to the receiver the frequency increases, if it is departing from the receiver the frequency decreases. The frequency change is in direct proportion with the velocity of the moving object. These frequency changes are called Doppler shift. If the ultrasound beam moves, the moving erythrocytes function as reflecting surface and they change the frequency of the reflected ultrasound. The Doppler shift can be described by the following equation:

$$f_d = \frac{2 \, x f_0 x \bar{v} x \cos \vartheta}{c}$$

where

f_d = Doppler shift
f_0 = frequency of the emitted sound
v = velocity of the reflecting surface
ϑ = angle between the direction of the ultrasound beam and the moving, reflecting object
c = velocity of the ultrasound in the examined material (in blood 1570 cm/sec)

The Doppler shift is audible for the human ear, provided that the frequency of the emitted sound is between 1–10 MHz. Hence, the changes of the velocity, or the velocity itself can be made audible.

The blood flow (Q) inside the examined vessel can be calculated with the help of the upper equation, as

Q = velocity x cross sectional area of the vessel

$$Q = v x \left(\frac{d}{2}\right)^2 x \, \pi$$

where

v = velocity of the blood
d = diameter of the vessel

A Kranzbühler 8130 Duplex Doppler apparatus was used in all of the examinations. The linear transducer (3 MHz) was connected with the Doppler transducer (2 MHz) to 50°, the direction of the Doppler ultrasound beam and the sample volume were controlled on the monitor. Frequency analysis was performed by a computer built in the machine using the Discrete Fourier Transformation.

The course of the examination was as follows. The position of the fetus was located by the linear transducer. The circumference of the abdomen was measured at the height of the umbilical vein, and the fetal weight was estimated on the basis of this result [9]. Subsequently, the Doppler ultrasound beam was directed to the fetal aorta and the sample volume was set. The fetal descending aorta was always examined just above the diaphragm, as the aorta has no branches here, so this part is free from the turbulent flow, which would distort the results. Each examination was performed in the period of fetal apnoea as the intrathoracic and intraabdominal pressure changes taking place as the result of the fetal breathing movement affect the blood flow [1, 3, 12]. Then the angle between the reflected ultrasound beam and the vessel was determined. The examined part of the aorta was enlarged and this diameter was measured repeatedly. Subsequently, on the basis of the average diameter, the apparatus calculated the quantity of the blood flow (ml/min) the result of which was read directly and divided with the estimated fetal weight.

The conclusion can be seen in *Figure 1*. *Left side up:* thorax of the fetus, aorta, direction of the ultrasound beam (dotted line), size of the reflecting ultrasound sign (traced line), and angle between the ultrasound beam and the vessel can be seen. *Left side, below:* enlarged picture of the examined part of the aorta. The diameter

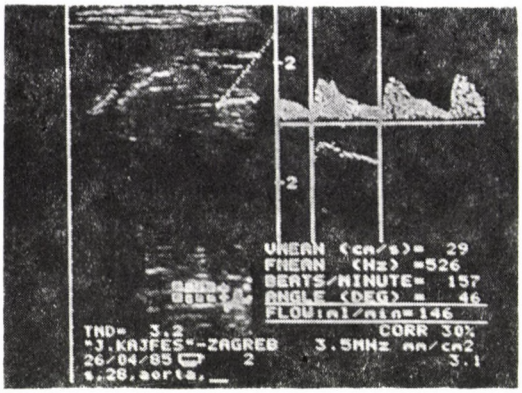

FIG. 1. Blood flow measured in the descendent part of aorta in a 28 weeks old fetus. (Description in text)

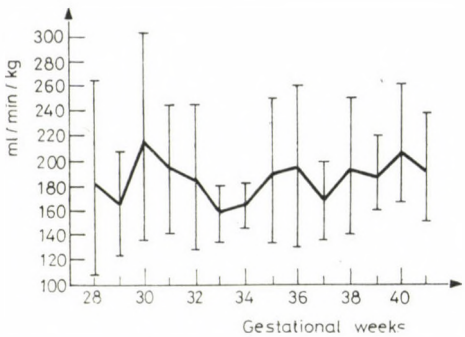

FIG. 2. Blood flow in the fetal aorta during the 28–41st weeks of pregnancy ($\bar{x} \pm SD$)

of the vessel was measured 5 times and the average value can be found just below it (TMD: 3.2). *Right side, up:* blood flow diagram characteristic with the fetal aorta Below that: blood flow velocity (29 cm/sec), mean frequency value (526 Hz), angle between the examined vessel and the ultrasound beam (46°), and blood flow (146 ml/min) can be read directly.

The waveforms of the blood velocity, that is the Doppler shift can be seen on the coordinate of the monitor and its values can be read on the ordinate, while the time on the abscissa.

Evaluation of the values was made using the A/B ratio [15], Resistance Index $\left(RI = \frac{A - B}{A}\right)$ [13] and Pulsatility Index $\left(PI = \frac{A - B}{\text{mean frequency}}\right)$ [7], where A = = systolic peak, B = end diastole.

The examination was unsuccessful in 8–10% of the women because of strong fetal trunk movements and fetal breathing; such cases were neglected.

Examination of intra-observer failure was made by Student's *t* test.

RESULTS

Blood flow volume in the fetal aorta showed approximately the same value in the third trimester (180–200 ml/min/kg) (Figure 2). Not taking into

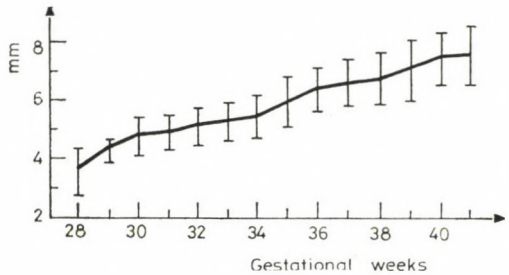

FIG. 3. Diameter of fetal aorta between the 28th and 41st weeks of gestation ($\bar{x} \pm SD$)

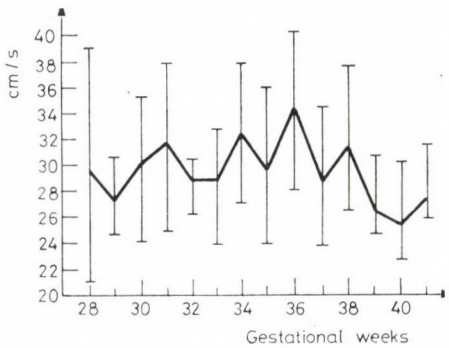

FIG. 4. Blood flow velocity in fetal aorta between the 28th and 41st weeks of gestation ($\bar{x} \pm SD$)

consideration the fetal body weight, but considering a fetus of about 1000 g at the beginning and 3000 g at the end of the third trimester, the blood flow increased about threefold (from 180—200 ml/min/kg to 540—600 ml/min).

The fetal aorta increased in diameter from 3–4 mm (28th week) to 7–8 mm (40th week) (Figure 3).

Blood flow velocity in the aorta fluctuated between wide limits (20–40 cm/sec), but the average value of 28–32 cm/sec seemed to decrease to 26–28 cm/sec after the 38th week of pregnancy (Figure 4).

Both the A/B ratio (4.0–5.0) and the Resistance Index (RI = 0.7–0.8) were practically at the same level during the third trimester. The Pulsatility Index was about 3.0 and increased moderately after the 38th week (Figure 5).

Examination of the intra-observer failure took place as follows: measurements were repeated every ten minutes in the same pregnant by the same examiner. A total of 10 pregnant women was examined in this way. No significant difference could be found ($p > 0.05$) in comparison of the two groups: concerning blood flow (ml/

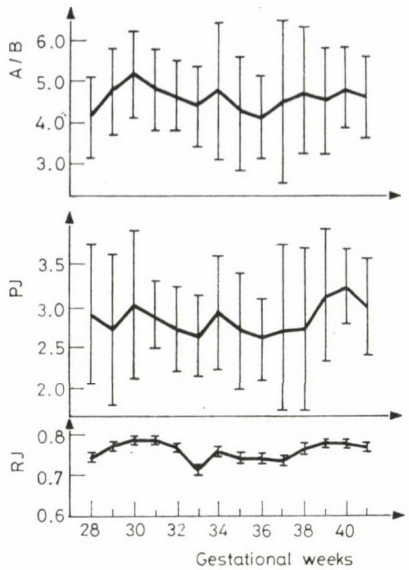

FIG. 5. A/B ratio, (A = systolic peak, B = end diastole), Pulsatility Index $\left(\frac{A-B}{\text{mean frequency}}\right)$ and Resistance Index $\left(\frac{A-B}{A}\right)$ in fetal aorta between the 28th and 41st weeks of gestation ($\bar{x} \pm SD$)

min/kg), the diameter of the aorta (mm), the velocity of blood (cm/sec) and the A/B ratio, Resistance Index and Pulsatility Index.

DISCUSSION

The waveform in the fetal aorta is biphasic, showing a continuous forward flow during the diastole. No reverse flow was to be seen (Figure 6). This is characteristic of an arterial blood vessel system of low resistance. Practically no change in the resistance of this system could be detected during the third trimester; this was demonstrated with the practically unchanged values of the A/B ratio, the Resistance Index as well as the Pulsatility Index. The shape of the waveform of fetal blood flow in the aorta underwent a significant change in the third trimester, though the indexes mentioned above did not demonstrate it. While Figure 1 shows the so-called "ski-slope"-like waveform characteristic of the 28th gestational week, Figure 6, which was produced in the 36th week, showed a much more complex waveform. The so-called "incisural notch" indicating the end systole could be seen, furthermore the change of systole and diastole as a function of time could distinctly be distinguished. Data in the literature concerning fetal aorta blood flow are not entirely homogeneous. Eik-Nes et al [2] examined 26 healthy fetuses between the 32nd and 41st weeks of pregnancy. In

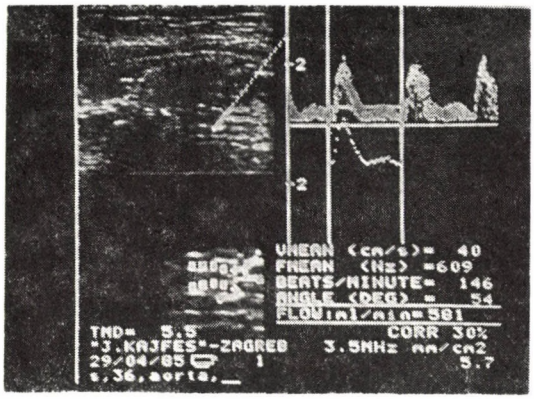

FIG. 6. Blood flow in descending aorta of a 36 weeks old fetus. *Left side*, above, cross-section of fetus and aorta. The direction of the Doppler beam is indicated by the dotted line, and at its end the traced line shows the sample volume of Doppler ultrasound. The straight line enclosing an angle of 54° with it, with a cross at the end, reveals the angle between the ultrasound beam and the examined vessel. *Left side, down:* enlarged part of the aorta. The squares and cross show its diameter. Measurement was repeated five times, the average can be read directly off the figure (TMD = 5.5). *Right side*, above specific waveform of the aorta. *Right side*, bottom calculated data can be read off

this period the blood flow in the descending part of the fetal aorta was 191 ± 12 ml/min/kg estimated fetal weight. Van Lierde et al [16] examined 20 healthy pregnants between the 32nd and 41st weeks of gestation; the blood flow found by them was 216 ± ± 24 ml/min/kg, and its velocity 27.7 ± 6.7 cm/sec. In 4 women between the 37th and 40th weeks of gestation Wladimiroff and McGhile [18] found a blood flow of 168–179 ml/min/kg. Thus, our results correspond best to those of Eik-Nes et al [2].

Blood flow velocity in the fetal aorta fluctuated between the limits observed by other authors [4, 8, 10].

The diameter of the aorta increased by about 50% from the beginning of the third trimester to its end, as reported by others [4, 10]. The blood flow compared to the estimated fetal weight remained approximately at the same level during the third trimester. Fetal weight increased about three times from the beginning of the first trimester to term; this means that if the blood flow was estimated without taking fetal weight into consideration, in ml/min it also increased three times by the end of the third trimester. This augmented blood flow must be attributed to changes of the fetal anatomical conditions, mainly to the increase of the diameter of the fetal aorta.

It is known from experiments on lamb fetuses [14] that about 70% of the fetal cardiac output reaches the descending part of the aorta, and cardiac output is about 800–900 ml in the human fetus at term [17]. Thus, in a term fetus of 3200 g, 640 ml/min blood may be calculated to flow in the descending part of the aorta, and this

corresponds well to the lamb experiments described above, i.e. that about 70% of the cardiac output reaches the examined part of the aorta.

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