

UMBILICAL CIRCULATION - PHYSIOLOGY AND PATHOLOGY

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It is important for the obstetrician to be aware of the possible mechanisms of umbilical blood flow disorders and the present report is intended to call attention to some of the facts involved. Animal experiments and observations in the human fetus make it clear that the disorders occurring to the umbilical circulation during pregnancy and during labor may be grouped into three categories:

1. **Chronic placental disorders** on the maternal side can lead to a reduction of the umbilical blood flow that is combined with fetal growth retardation.
2. **Mechanical compromise** of the umbilical circulation is provoked by twisting of the umbilical cord around the fetal neck or simply due to location of the umbilical cord next to the fetal head and
3. the **vascular resistance** of the umbilical circulation may increase due to repetitive hypoxic episodes generated by cord occlusion or the reduction of uterine blood flow.

UMBILICAL BLOOD FLOW DURING PREGNANCY AND IN GROWTH RETARDATION

In order to meet the requirements of the growing fetus it is conceivable that uterine blood flow, which provides the nutrients and the oxygen to the fetus, and umbilical blood flow, which receives nutrients and oxygen are rising throughout pregnancy. The only data which describe the course of uterine and umbilical blood flow during pregnancy in the human fetus were provided by ASSALI et al. (1960) (2) in pregnancies who were subjected to abortion for different reasons. With increasing uterine blood flow the umbilical blood flow is also rising. There is a tenfold increase from the 12th week of gestation to the 28th week of gestation. Related to the weight of the fetus the umbilical blood flow remains fairly constant and is about 110-120 ml/kg/min throughout gestation. This blood flow is of the same magnitude as has been measured in the umbilical vein in the newborn immediately after birth (11). It may be assumed, that this tremendous increase in umbilical blood flow is favoured by the rise of the uterine blood flow that is directed to the maternal side of the placenta.

Experiments in the chronic sheep preparation by CREASEY et al. (1972) (3) demonstrate, that following embolization of the uterine vascular bed with microspheres umbilical blood flow decreased in parallel with uterine blood flow. Umbilical blood flow in the control group was 158 ml/kg/min (SE = 14) and in the embolized group 109 ml/kg/min (SE = 7), a significant difference. It has to be emphasized that the PO_2 in the arterial blood of the fetus was also reduced: 17 mmHg in the embolized group compared to 23 mmHg in the control.

If we consider the fetus which is located in one uterine horn of a uterus didelphys or the fetus of an eclamptic or preeclamptic patient we may suppose that similar conditions are present in the human as in the experimental model. Reduced umbilical blood flow may be a result of the diminished nutrient and oxygen supply to the fetus as a result of the reduction in uterine blood flow.

The cardiac output however remains roughly unchanged if related to the weight of the fetus. The percentage of cardiac output directed to the placenta under physiological conditions is about 50 %. It decreases to 30 % when uterine blood flow falls. The cardiac output is redistributed favoring the fetal brain and the fetal heart (3).

THE MECHANISM OF CORD COMPRESSION DURING LABOR AND ITS RESPONSE ON FETAL OXYGENATION

For the understanding of umbilical blood flow disorders which can occur during labor it is of importance to know the factors which regulate the umbilical circulation. Umbilical blood flow is dependend on the perfusion pressure which is given by the pressure in the fetal aorta (pa) and the pressure in the umbilical vein (pv) Fig. 1).

Umbilical blood flow is proportional to this pressure difference, i.e. umbilical blood flow falls if the blood pressure in the aorta decreases and if the blood pressure in the umbilical vein rises. Umbilical blood flow is however also inversely related to the resistance offered by the umbilical and placental vessels (R_T) and factors which influence the resistance of these vessels e.g. isolated artery compression can decrease the flow in this system.

It has been known to obstetricians for a long time that the umbilical circulation is protected by the amniotic fluid and that loss of the amniotic fluid may lead in some cases to compression of the umbilical cord and subsequent deterioration of the fetus. From the theoretical point of view the umbilical circulation is not disturbed during uterine contractions for the following reason: The uterus may be considered as shown in

UTERUS

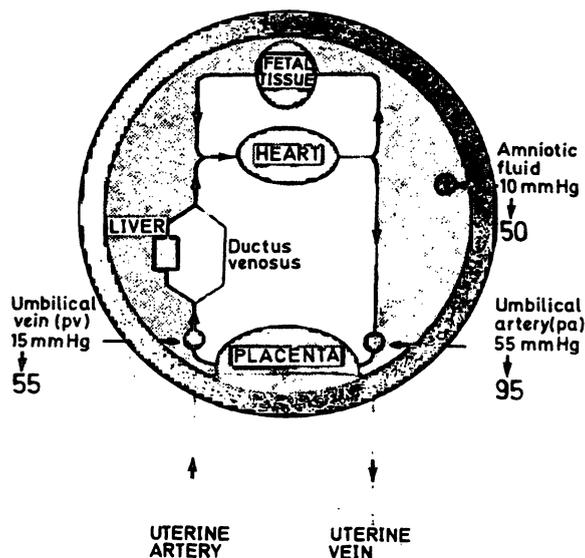


Fig. 1 as a hollow sphere which is filled with incompressible contents: the fetus, the amniotic fluid and the placenta. When the uterus contracts the pressure in each compartment within the sphere will increase by the same amount so that the perfusion pressure, which is responsible for a constant flow will not fall. During the contraction of the uterus only the uterine circulation will be compromised. Although the umbilical circulation is protected under physiological conditions many disturbances may occur especially during labor. A most common phenomenon for the obstetrician and evidence of cord compression is the variable heart rate deceleration pattern observed during labor. Abnormal cord position in the human is associated with a variable deceleration pattern or a mixed cord compression pattern of the fetal heart rate in 84 % of all cases (6). Premature rupture of membranes and the loss of amniotic fluid may favour the compression of the umbilical cord. In cases of breech deliveries variable decelerations of fetal heart rate resulting from reduction of umbilical blood flow occur more frequently. The sudden death of the fetus following an intrauterine transfusion may also be caused by a reduction in umbilical blood flow due to elevation of the intraabdominal pressure. This has been proven in animal experiments in monkeys (4).

$$Q_{umb} = (p_a - p_v) \cdot \frac{1}{R}$$

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Mechanism of flow reduction: What is the mechanism of the reduction of umbilical blood flow? In experimental studies in the sheep fetus we have examined the mechanism of umbilical vein occlusion (8). Umbilical blood flow was measured in one umbilical artery and the common umbilical vein was occluded by an inflatable cuff placed around it. The Fig. 2 shows the umbilical blood flow and the response of the blood pressure in the fetal aorta and in the umbilical vein distal the point of occlusion. Starting with the occlusion of the umbilical vein there was an increase in umbilical vein blood pressure which was much more pronounced than the arterial blood pressure elevation. This indicates a fall in perfusion pressure and simultaneously a reduction in umbilical blood flow occurred.

This reduction in umbilical blood flow was accompanied by a small decrease in the vascular resistance of the umbilical circulation during the initial seconds following occlusion of the umbilical vein. Thereafter a linear fall in the blood flow occurred with decreasing perfusion pressure.

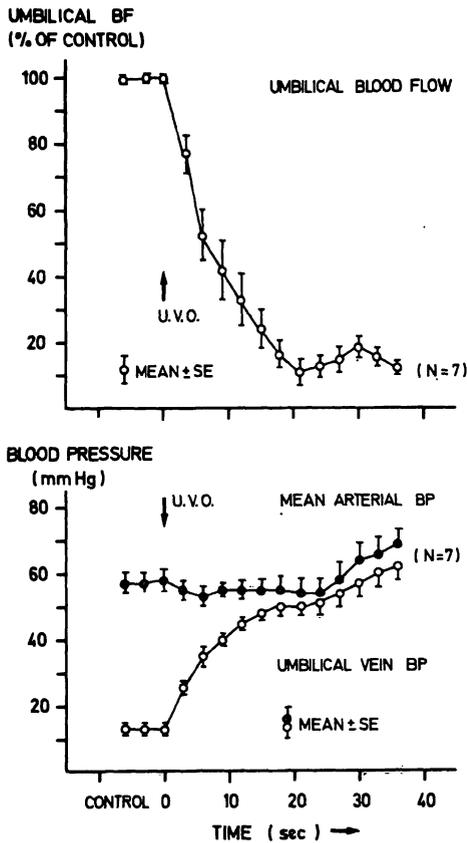


Fig. 2

Umbilical blood flow and the blood pressure in the fetal aorta and the umbilical vein prior and following umbilical vein occlusion (UVO).

Umbilical blood flow and fetal oxygen

consumption: The question arises whether mild compression of the umbilical cord resulting in mild reduction of umbilical blood flow is deleterious to the fetus in terms of its oxygenation and whether there are any buffer mechanisms of the cardiovascular system available. According to DAWES (5), RUDOLPH (10) and other investigators it is known that the range of the physiological blood flow in the sheep fetus is about 150-200 ml/kg/min. The oxygen saturation in the umbilical vein at this flow rate is about 80% and in the umbilical artery 70%. There is only a slight change in umbilical artery SO_2 when flow changes in the range of 150 and 200 ml/kg/min, thus one can postulate that an umbilical circulatory buffer exists at physiological umbilical blood flow rates. The umbilical artery SO_2 decreases however proportionately when the flow is reduced below 100 ml/kg/min. The umbilical vein SO_2 remains constant even if umbilical blood flow decreases indicating a normal uterine blood flow in these cases.

A constant oxygen saturation in the umbilical vein and a fall of the SO_2 in the umbilical artery demonstrate that the reduction of umbilical blood flow is accompanied with an increase in the arterio-venous oxygen difference.

Under the assumption of a constant oxygen uptake as shown in Fig. 3,

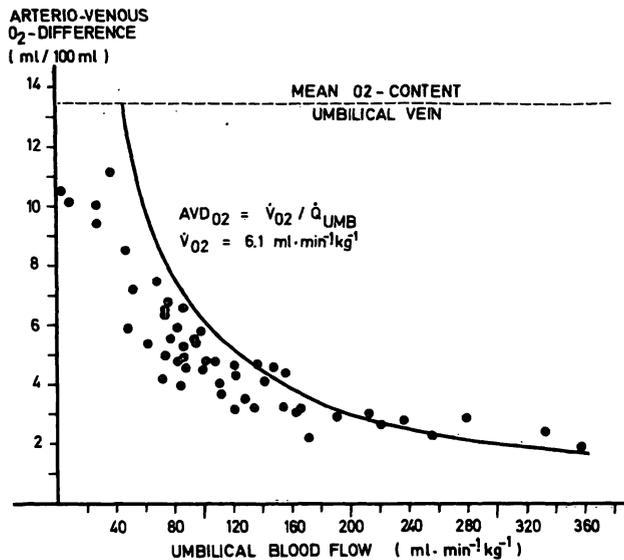


Fig. 3

The relationship between the arterio-venous- O_2 -difference and umbilical blood flow (UBF). The solid line shows the theoretical relationship between UBF and $AVDO_2$ at a constant O_2 -consumption of 6.1 ml/min/kg.

The measured values deviate from the solid line at a flow rate of 120 ml/kg/min indicating a fall of O_2 -uptake.

the AV O_2 -difference should increase along the solid line if umbilical blood flow falls. The measured values however deviate from the solid line i.e. the oxygen uptake of the fetus is compromised whenever the

flow falls below 120 ml/kg/min. The fetal arterial oxygen saturation at this point is about 50%, a value which was already established in former observations by ACHESON, DAWES and MOTT (1957) (1).

The cardiovascular response of the fetus is closely related to the alteration of the umbilical blood flow.

UMBILICAL BLOOD FLOW IN FETAL SHOCK

It is known from the clinical management and from animal experiments (7, 9) that occasional hypoxic episodes of short duration are of no harm to the fetus. However, if they are frequent and long lasting the effect on the fetus may be deleterious. Acute experiments in the sheep fetus show a relationship between repetitive stress and deterioration of the fetus.

The pH in the fetal blood under such circumstances is a good measure of the deterioration. If correlated with the mean arterial blood pressure it is evident that with decreasing pH the mean arterial blood pressure falls ($p_a = 56.8 \cdot \text{pH} - 368$) ($2\alpha < 0.001$). At normal pH of 7.40 the blood pressure was about 50 mmHg and at a pH of 7.10 the blood pressure was 30 mmHg.

With falling blood pressure a reduction of the umbilical blood flow occurs. There is however no linear relationship between blood pressure and umbilical blood flow ($\log Q_{\text{umb}} = 1.14 + 0.02 \cdot p_a$) ($2\alpha < 0.001$). Small blood pressure changes are accompanied by a steep fall in umbilical blood flow, which is caused by an increase in umbilical vascular resistance. This is an important relationship because it emphasizes that the umbilical blood flow falls with the development of the fetal shock.

Summary and conclusions:

1. The umbilical circulation under physiological conditions is protected by the amniotic fluid. This protective mechanism of the amniotic fluid may be disturbed arteficially or spontaneously by the rupture of the membranes.
2. Umbilical cord compression is of no harm to the fetus when it is mild, since the fetus possesses a circulatory buffer system when umbilical blood flow is in a physiological range. However, severe reduction of umbilical blood flow may lead to fetal hypoxia.
3. Chronic or repetitive acute fetal hypoxia leads to deterioration of fetal circulation and umbilical blood flow. This can be recognized by the obstetrician during labor based on fetal heart rate patterns.

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