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ORIGINAL ARTICLE

Functional morphology of ductus venosus in human fetus

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Abstract

OBJECTIVES: The morphology of region umbilical vein, umbilical sinus and ductus venosus of human fetuses have been investigated.
MATERIAL AND METHODS: 26 human fetuses between 20 and 40 weeks' gestation were examined by morphological methods. The umbilical vein, DV and the portal vein were obtained after termination of gestation. Tissue samples have been fixed in phormaldehyde solution (pH 7,2) and were embedded in paraffin. The paraffin sections (5–7 μk) were stained with hematoxylin and eosin, silver impregnation by Bilchovski, orcein, pikrofuchsin. Measurement of the angle between ductus venosus and the portal vein was obtained with alidade.
RESULTS: Anatomical scheme of the region of umbilical vein, umbilical sinus and DV indicating two different patterns. The first: DV has situated into line with umbilical vein (22 cases). The second: umbilical vein has rotated before umbilical sinus, forming the turn in right (4 cases). The double-layer wall of ductus venosus (DV) contained the elastic, collagen and argyrophilic fibers. Around isthmus region of DV vasa vasorum and nervi vasorum have been found. The specific anatomical finding of the ductal isthmus was an accumulation of smooth muscle cells as intimal pillow, which were protruded into the vascular lumen. The double-layer wall of portal sinus (intima and adventitia) have been as the internal elastic membrane. The smooth muscle cells have been revealed in the walls, were not formed the tunica media at term 20–40 weeks of gestation. By the contrast the umbilical vein showed multiple, circularly running smooth muscle bundles. In this study, the ductal thickness was consistently bigger in the inlet than in the outlet. The tunica adventitia was greatest in the junction with the portal sinus and the inferior vena cava compared with the part arranged in the liver parenchyma. The wall thickness of the portal sinus and of the umbilical vein was significantly higher than of the duclal wall.
CONCLUSION: The vascular muscle-elastic cells of intimal hyperplasia ("intimal pillow") in wall of DV, probably, executes the role of the fortification of resistant behaviours of vessel wall in connection with DV and portal sinus with high hemodynamics load in this area. The maximum thickness of adventicia in the field of joints also witnesses an hemodynamic in favour of particularities. The angle between DV and left branches of portal vein in dominate cases was sharp and right that reflects the general regularity of architectonics of the vascular riverbed.

Introduction

THE DUCTUS VENOSUS (DV), firstly described in the human fetus by the anatomist Giulio Cesare Aranzio in the sixteenth century, is a narrow, trumpet-shaped vessel in the fetal liver. It directly connects the umbilical vein to the inferior vena cava in the proximity of the right atrium. This vessel plays a crucial role in the fetal circulation because it shunts highly oxygenated and nutrient-rich umbilical venous blood to the brain and myocardium instead of the fetal liver [30]. This role has been demonstrated by experiments on the fetal primates [3], as well as on the fetal sheep [29, 12, 11] and even on previable human fetuses [28].

Since the color Doppler imaging was developed in 1991–1992, this small venous vessel has become the object of extensive clinical research in the human fetus, and the velocity waveform in DV has been proposed as a relevant indicator of fetal well-being [19, 20, 26]. It has been estimated that, during induced hypoxia or reduced umbilical flow in fetal sheep, the blood flow shunted through the DV increases and could reach as much as 70% of the umbilical blood flow [10]. The active dilatation of DV [2, 15] and the increased shunting was also observed for the first time by Bellotti *et al*. [4] in two human fetuses with intrauterine growth retardation (IUGR).

However, in contrast to velocity measurements, blood flow through the DV in the human fetus has not been investigated extensively [25, 33] because of the technical difficulties involved. The anatomic features of this trumpet-shaped vessel as well as the unusual geometry of DV branching from the intrahepatic umbilical vein are responsible for complex hemodynamics [27]. These conditions suggest that the caution should be exercised in the clinical interpretation of simple Doppler velocimetric indexes [26].

Furthermore, it has been impossible to assess the ductal flow and its changes during gestation in any animal species. There are many reasons for this, but it heightens the importance of these studies for the human fetus.

Materials And Methods

26 human fetuses between 20 and 40 weeks' gestation were examined by morphological methods. The umbilical vein, DV and the portal vein were obtained after termination of gestation. Tissue samples have been fixed in phormaldehyde solution (pH 7,2) and were embedded in paraffin. The paraffin sections (5–7 μk) were stained with hematoxylin and eosin, silver impregnation by Bilchovski, orcein, pikrofuchsin.

Measurement. Measurement of the angle between ductus venosus and the portal vein was obtained with alidade.

Results

The umbilical vein continued to the umbilical sinus, which joined the ductus venosus and the portal vein (portal sinus). Anatomical scheme of the region of umbilical vein, umbilical sinus and DV indicating two different patterns. The first one is: DV has situated into line with umbilical vein (22 cases). The second one: umbilical vein has rotated before umbilical sinus, forming the turn in right (4 cases). The measurement of the angle between the ductus venosus and the portal vein might correlate with ultrasonographic parameters of hemodynamics. In the groups study, the angle have been sharp (10 cases), right (11 cases) and obtuse (5 cases).

Traditional hematoxylin-eosin and staining by van Gison of tissue sections sufficed to show the tunica intima and the adventitia in DV walls. The smooth muscle cells in the walls were uniformly distributed along the vessel's course, but they could not be convincingly identified as tunica media. Also the wall of DV contained the elastic, collagen and argyrophilia fibers. Around isthmus region of DV vasa vasorum and nervi vasorum have been found. The specific anatomical finding of the ductal isthmus had been an accumulation of smooth muscle cells as intimal pillow, which were protruded into the vascular lumen (Fig. 1).

The double-layer wall of portal sinus (intima and adventitia) have been as the internal elastic membrane (Fig. 2). The smooth muscle cells have been revealed in the walls, were not formed the tunica media at term 20–40 weeks of gestation. The mesenchymal cells, arteries, bile-ducts and nerve fibers have been seen in the circumference of portal sinus.

By the contrast the umbilical vein, had the internal elastic membrane, formed at the boundary with intima and media, showed multiple, circularly running smooth muscle bundles. In the region of the portal sinus the thickness of media decreased up to several lines of smooth muscle cells (Fig. 3).

In the groups study, the ductal thickness was consistently bigger in the inlet than in the outlet (Table 1). The tunica adventitia was greatest in the junction with the portal sinus and the inferior vena cava compared with part arranged in the liver parenchyma.

The wall thickness of the portal sinus and of the umbilical vein was significantly higher than of the duclal wall.

Discussion

Autonomic regulation of blood flow through the fetal ductus venosus has been suggested, but the exact mechanism, determining a flow, is still unknown. Determination of a similar muscular activity in the human fetus is quite controversial because of the lack of anatomic evidence of such a structure and observations of diameter dilatation *in vivo*.

Similar sphincteric activity was speculated in the human fetus [4], but this occurrence is quite controversial. In the lamb, Coceani *et al*. [7] have been reported

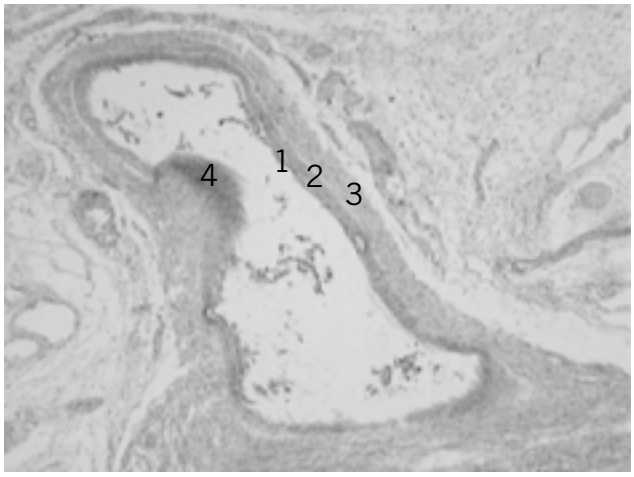

Fig. 1. The ductus venosus (inlet). 1 – tunica intima, 2 – tunica media, 3 – tunica adventicia, 4 – intimal pillow. Hematoxylin-eosin. X40

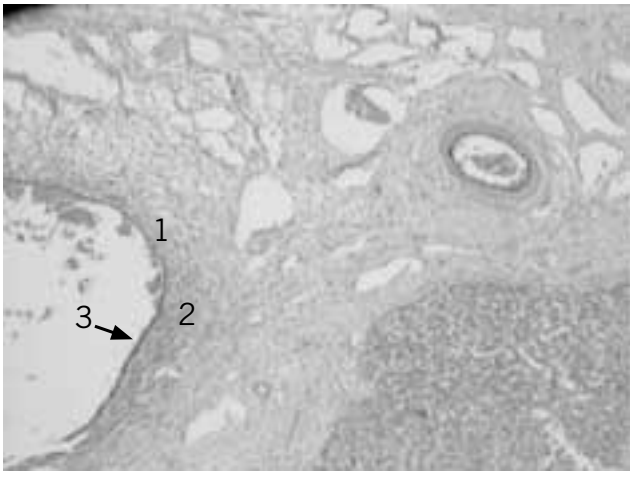

Fig. 2. The double-layer wall of portal sinus (1 – intima, 2 – adventitia) have been as the internal elastic membrane (3). Pikrofuchsin. X40

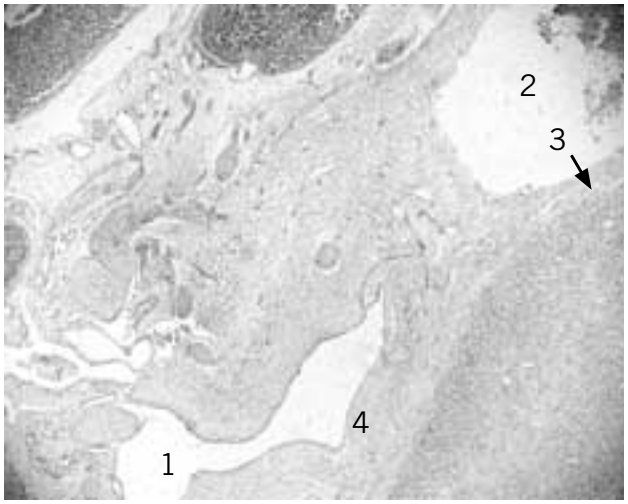

Fig. 3 (left). The region of the portal sinus. 1 – umbilical vein, 2 – portal sinus, 3 – tunica media of portal sinus, 4 – tunica media of umbilical vein. Hematoxylin-eosin. X20

Table 1.
Mean thickness wall of DV, portal sinus and umbilical vein

Vessel segment	n	M±m (mm)	P
Ductus venosus (inlet)	9	0,12	<0,0001
Ductus venosus (outlet)	12	0,05	<0,0001
portal sinus	17	0,23	<0,0001
umbilical vein	8	0,26	<0,0001

about adrenergic and cholinergic fibers in both the sphincter and extrasphincter regions of DV. The influence of prostaglandins on the vessel lumen diameter was established experimentally [31].

The term 'venous sphincter' specifically defines the tufts of smooth muscle cells subjacent to the endothelium inside the elastic lamina and separated by connective tissue elements. These sphincters are capable of active spontaneous contraction, also they are involved in blood flow regulation, and respond to vasoactive substances. The regulation of venous blood flow are caused by smooth muscle hoops and smooth muscle 'pillows'. In some cases smooth muscle hoops arised from circular muscle layer of media in other places they settling under endothelium, protruded into the vascular lumen [5]. The physiologic aspects of the sphincter mechanisms have been greatly clarified mainly in postnatal development, developing central rules of sphincterology [21, 22].

Our study reveals the accumulation of smooth muscle cells as intimal pillow, setting in the isthmus region DV. It is possible to suggest that intimal pillow has been formatted by the vascular muscle-elastic cells of intima under their hyperplasia. Earlier, the same objects were described in the literature at the branching sites of human intracranial arteries. In fact, there are local hyperplasia of the internal elastic layer, situated to the branching sites. These structures have been know as 'Rotter's pillow' on the name of the author who has described them in the field of branchings sites of human intracranial arteries. Volkova in detail described their morphology in brain arteries more than 20 years prior to opening Rotter W. *et al*. [34]. It is important to emphasize, that in the area branchings intracranial arteries in children them find seldom, and in adults they are present practically at everyone vessel junction [32]. The vascular muscle-elastic hyperplasia was distinguish muscle, elastic and mixed forms. In our study we obtained the mixed form of vascular muscle-elastic hyperplasia. The role of intimal pillow in the regulation of hemodynamic has been investigated in few publications. The intimal pillow might be obstacle of blood flow *i.e.* the formations creating hemodynamics instability in the area branchings vessels [27]. In 1973, Northfield disclaimed any role of vascular muscle-elastic hyperplasia in active regulation of flow [24]. He suggested that the intimal pillow is the result of passive transformations of intima, caused by hemodynamic stress, for example an vorticity, difference of vessel pressure.

The vascular muscle-elastic hyperplasia might be considered as the compensatory formation in the reply to degenerate changes in the internal elastic membrane in the area branching vessels [8]. It this postulate is right, the vascular muscle-elastic hyperplasia plays a role of counteractive force, strengthening a vessel wall. This opinion agree is supported by Medvedev, Zabrodskaya [23], who consider, the intimal pillows as not only the result of hemodynamic stress, but also as masks connection by two located muscle metamer ('media's defect') of two vessels.

Therefore, our data show that media's defect in connection of vessels were not revealed, caused by poorly developed tufts of smooth muscle cells in the venous walls in prenatal period. Formative mechanism of the vascular muscle-elastic cells of intimal hyperplasia, described by some authors, was significance migration of smooth muscle cells inside subendothelial layer through the natural holes internal elastic membrane. Probably, the function of intimal pillow in connection with umbilical vein and DV is directed on the conservation of wholeness and protection from sprain ductal wall since given area is characterized by the high hemodynamic load (hemodynamic stress). Besides, the correlation of construction of connection vessels and particularities of hemodynamics is repeatedly described in literature [6, 16, 23]. Exactly there is attention paid to variants of topography DV and branching umbilical vein with left branch an portal vein as well as the angle between DV and left branch an portal vein. The turn in rifht (4 cases) of umbilical vein probably might be connected with embryonic stages of DV. At 4–5 weeks after fertilization the left half of the subhepatic anastomosis has rotated into the line with the umbilical vein. Therefore, the subhepatic anastomosis becomes the terminal part of the umbilical vein [9].

The data of measuring angles show the domination of sharp and right angles. Azarova [1] described the intersection of hepatic portal veins nearly under right angle. The angle of bifurcation small branch is right or nearly right angle. This reflects the general regularity an architectonics of vascular channel, than larger branching dissymetric, that more angle of deflection of fine branch in contrast with thick branch [6]. The constructive stability of branching (the segments), matching with optimum location of circulatory tree in any organ, can be violated under the influence of different factors, in prenatal as well as in postnatal period under already formed vascular riverbed [6]. Four fetuses with chromosome aberrations (trisomy 21) and one with streptoccocus pneumonia have the obtuse angle.

A blood pressure, influencing on the value of voltage of vascular wall, in the region of branching vessels is 30% above, than in line segments [14].

The value of voltage of the vascular wall is defined the value of transmural pressure (the value of venous pressure minus value of external pressure), as well as value of vascular lumen. The construction of the wall correlated with its tension [18]. However, the wall of different vessels contains various structured components (smooth muscle, elastic and collagen tufts) have been obtained in the different quantitative correlations. So, the umbilical vein show circularly running smooth muscle bundles of media, in contrast to the portal sinus and DV where exists several lines of smooth muscle cells. This points that their development is not defined wholly alike factors. The smooth muscle bundles, causing both reduction of wall, and active resistance to sprain of vessel, its development must to be correspond to the value of container`s voltage of wall.

The correlation determined between the degree of development elastic and collagen elements and the value of voltage of venous wall exist. The elastic tufts resist increasing action of transmural pressure as well as action of external factors. The longitudinal elastic tufts of media and intima realize the delay narrowing actions of circular muscle tufts and prevent overweening vasoconstriction. In our study elastic tufts are found in three layer of wall umbilical vein, portal sinus and DV.

The external pressure in veins, sited inside organs, counterbalances in significant and/or to a complete measure venous pressure. Therefore the transmural pressure in this veins is low or absent. This confirmation is the wall of DV, where were revealled the elastic tufts.

The load on the part of lumen vessel perceive and reflect intima and media then load outside perceives adventicia of vessel. So, thickness of wall umbilical vein most that corresponds to the powerful highly oxygenated flow, going from placenta (the expression of adaptation to external influences). DV had the least thickness of wall that is explained its location in furrow between lobus sinistra and lobus Spigelii. Since DV has the funnel-shaped the hemodynamics load, falling on internal tunica in the field of its isthmus, increases. With this is bound most thickness an adventicia of wall DV in this area.

Thereby, the vascular muscle-elastic cells of intimal hyperplasia ("intimal pillow") in wall of DV, probably, executes the role of the fortification of resistant behaviours of vessel wall in connection with DV and portal sinus with high hemodynamics load in this area. The maximum thickness of adventicia in the field of joints also witnesses an hemodynamic in favour of particularities. The angle between DV and left branches of portal vein in dominate cases was sharp and right that reflects the general regularity an architectonic of vascular riverbed.

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